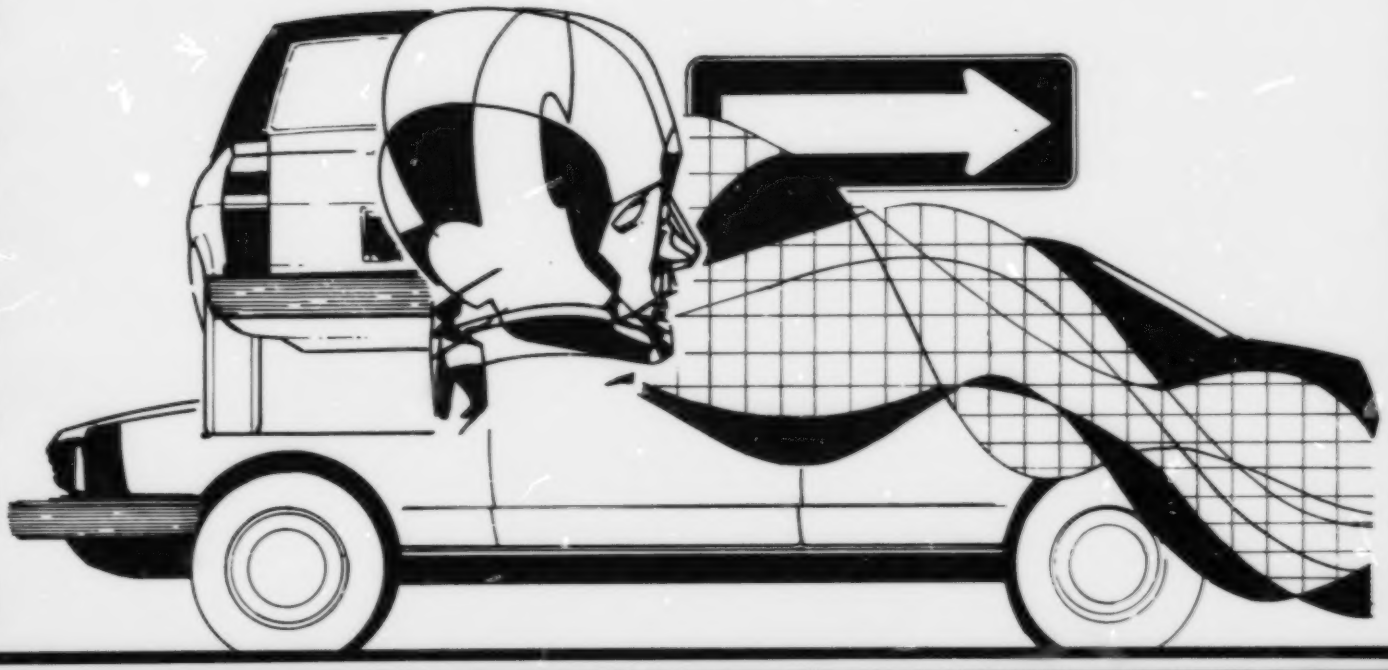
TP 8445E

SCHOOL BUS SEAT DEVELOPMENT STUDY



CA1
DTC 132
87
S11

Transport Canada
Road Safety

Transports Canada
Securité routière

Canada

CA1
DTC132-
87
S11

372704

41.D

Library and Information Centre /
Centre de Documentation (GSLA)
RECEIVED - REÇU LE
OCT 5 1987
Transport Canada / Transports Canada

SCHOOL BUS SEAT DEVELOPMENT STUDY

Prepared For: Traffic Safety Standards and Research
Transport Canada

Prepared By: G.N. Farr, P. Eng.
Automotive Safety Engineer
Crashworthiness Section

Date: April 1987

91-02953/

REPORT DOCUMENTATION FORM

1 Transport Canada Report No	2 TDC Project No	3 Recipient's Catalogue No
TP 8445 E	-	

4 Title and Subtitle	5 Report Date
School Bus Seat Development Study	April 1987
	6 Performing Organization Report No: TP 8445 E

7 Author(s)	8 Transport Canada File No
G.N. Farr, P.Eng.	ASF 3291-10-4

9 Performing Organization Name and Address	10 DSS File No
Transport Canada Road Safety & Motor Vehicle Regulation Crashworthiness Section	485Z-T8080-7-0242
	11 DSS or Transport Canada Contract No: 0SZ85-00139

12 Sponsoring Agency Name and Address	13 Type of Report and Period Covered
Same	FINAL
	14 Sponsoring Agency Code

15 Supplementary Notes	16 TDC Project Officer
This report supplements report TP 6222 E "School Bus Safety Study"	-

17 Abstract

This report describes a study undertaken in 1986 to investigate five possibilities for installing seat belts on school bus seats. Two alternatives were judged feasible; three-point belts and rear-facing seats.

18 Key Words	19 Distribution Statement
Seat belts School bus safety School bus seats School bus	Public

20 Security Classification (of this report)	21 Security Classification (of this page)	22 No of Pages	23 Price
UN	UN	75	-

TDC CDT 79.005

ACKNOWLEDGEMENTS

The author of this report gratefully acknowledges the assistance provided by the Staff of Davis Engineering who acted as the contractor to design, build and oversee the testing of the seating concepts. Mr. Don Day and Mr. Dave Dennison of the Defence and Civil Institute for Environmental Medicine, where the sled tests were conducted, provided invaluable assistance as well.

Thanks are also extended to Mr. T.M. Burtch, Mr. R.V. Myers and Mr. W. Gardner of Transport Canada for editing the manuscript and providing helpful comments and suggestions and to Lynda Lackey who typed the manuscript and persevered through the many revisions and corrections.

TABLE OF CONTENTS

	Page
Table of Contents	i
List of Tables	ii
Summary (English)	1
Résumé (French)	4
Background	7
Introduction	9
Approach	11
Dynamic Sled Testing of Seats	11
Testing Facility and Instrumentation	12
Pretest Setup	12
Results	14
Preamble	14
Forward Facing Seats with Lap Belts Only	15
Contoured Padded Seat Back	16
Less Aggressive Seat Back	18
Seats with Lap and Shoulder Belts	19
Three Point Restraint System	20
Multi Point Restraint System	20
Rearward Facing Seat	22
Costs	26
Supplementary Tests	28
Frontal-Unbelted ATD - Contoured Padded Seat	28
Frontal-Less Aggressive Seat	29
Frontal-Three Point System - Two ATD's on Seat	29
Frontal-Rearward Facing Seat - Three ATD's on Seat	30
Miscellaneous	33
Retractors	34
Conclusions	36
Recommendations	37
Photo Index and Photos	38
References	75

LIST OF TABLES

	Page
Table 1 - Peak Sled Velocity and Acceleration	23
Table 2 - Head and Chest Accelerations and HIC Value	23
Table 3 - Maximum Seat Belt Loads	24
Table 4 - Maximum Femur Loads	24
Table 5 - Approximate Deflections at Top Centre of Seat Back	25
Table 6 - Production Cost Increase Estimates	27
Table 7 - Supplementary Sled Test Results	32

SUMMARY

In order to investigate possible methods of improving the protection provided to school bus occupants, a project was initiated to design, construct and test five different seating concepts, each employing a restraint system (lap belt, lap-shoulder belt or harness).

Modifications were made to a standard .99 m (39 inch) Blue Bird seat with manual seat belts, in order to meet the specific requirements for each of the new concepts.

In addition to these five new designs, a standard Blue Bird bus seat with lap belts was also tested to provide baseline data for comparison purposes.

The five seats which were designed, constructed and tested were as follows:

1) Contoured padded seat back and lap belt combination

   This design included additional padding on the top and rear of the seat back.

2) Less aggressive seat back and lap belt combination

   The top portion of the seat back frame was modified to allow greater seat back deflection when struck from the rear.

3) Rearward facing seat with lap belt

   The seat was turned to face the rear of the bus and the seat back was increased in height and reinforced.

4) Three-point restraint system

   This seat incorporated an automotive type lap and shoulder belt requiring that the seat frame structure be considerably reinforced.

5) Multi-point restraint system

   This seat incorporated a harness type restraint, consisting of a lap belt and two shoulder straps. The seat frame structure was again considerably reinforced.

All seat belt systems, with the exception of the unaltered seat and the multi-point restraint system, incorporated emergency locking retractors.

The testing of the seats was conducted using the Hyge impact test facility at the Defence and Civil Institute for Environmental Medicine (DCIEM) in Toronto. Both head-on and oblique (30 degrees from head-on) tests were performed at a deceleration of 30g's from 48 km/h (30 mph). Instrumented 5th percentile adult female anthropomorphic test devices were used to acquire test data for head and chest acceleration, femur and seat belt loads. High speed filming of each of the tests was also done to assist in the analysis of the results.

The test results can be summarized as follows:

1) Contoured padded seat back

   The results were essentially the same as those for the standard unaltered seat.

2) Less aggressive seat back

   The peak head acceleration was significantly lower and the chest acceleration was somewhat lower than for the unaltered seat. However, the Head Injury Criteria (HIC) value was essentially the same as that calculated for the unaltered seat.

3) Rearward facing seat

   This seat showed a significant reduction in all recorded injury criteria, compared to the standard unaltered seat.

4) Three point and multi-point restraint systems

   Both these systems significantly reduced the head acceleration and HIC, but not the chest acceleration.

CONCLUSIONS

The following conclusions can be drawn from this test program:

1. The rearward facing seat was effective in reducing all injury levels to acceptable values.

2. The upper torso restraint on the three-point system reduced the head injury (HIC) value to acceptable levels but did not improve the resultant peak chest acceleration. However, if a three-point restraint system is used, it is imperative that the occupant wear the belts due to the increased stiffness of the seat structure.

3. The two systems which used modified forward facing seats and lap belts only were not effective in reducing the head injury criteria (HIC) to acceptable levels.

4. The multi-point seat belt system was cumbersome to use and permitted submarining of the test ATD.

5. The location of the retractors on the lower seat frame must be re-examined to prevent possible damage by leg contact from the rear.

6. The modifications for the three systems which employ lap belts only cost below $60 per seat. The modifications for the two systems which incorporate upper torso restraint cost in excess of $115 per seat. Retractors represent the most significant increase in cost for all systems.

RESUME

Pour examiner les méthodes possibles d'amélicrer la protection offerte aux occupants d'un autobus scolaire, une étude a été effectuée pour créer, fabriquer et mettre à l'épreuve cinq sortes de sièges munis d'un système de retenue différent (ceinture sous-abdominale, combinaison de ceinture sous-abdominale et de ceinture baudrier, et système de retenue à attaches multiples). Certaines modifications furent apportées au siège de 0.99 m (39 po.) fabriqué par Blue Bird et équipé de ceintures manuelles, pour satisfaire aux exigences spécifiques de chacuns des modèles. En plus des cinq modèles de prototypes, un siège standard de Blue Bird avec ceintures sous-abdominales à aussi été mis à l'essai pour fournir les données de base à titre de comparaison.

Les cinq sièges qui ont été créés, fabriqués et mis à l'essai sont ceux qui suivent:

1. Combinaison d'un rembourrage contournant le dossier du siège avec ceinture sous-abdominale

   Ce modèle comprenait du rembourrage supplémentaire à l'arrière et au-dessus du dossier du siège.

2. Combinaison d'un dossier de siège moins rigide avec ceinture sous-abdominale

   La charpente du dossier du siège était modifiée pour permettre un amortissement plus efficace quand il était enfoncé de l'arrière.

3. Siège faisant face à l'arrière avec ceinture sous-abdominale

   Ce siège était renversé pour faire face à l'arrière de l'autobus scolaire et le dossier du siège avait été élevé et renforcé.

4. Système de retenue à trois attaches

   Ce siège comprenait une ceinture sous-abdominale et une ceinture baudrier telle qu'installée dans une voiture. Il avait été nécessaire de renforcer considérablement la charpente du siège.

5. Système de retenue à attaches multiples

Ce siège comprenait une ceinture sous-abdominale et deux ceintures baudriers. La charpente du siège était aussi considérablement renforcée.

Toutes les ceintures de sécurité étaient munies d'un rétracteur à blocage d'urgence, à l'exception de celles à attaches multiples et au siège standard.

L'essai des sièges a été effectué en employant le simulateur à l'épreuve d'impact Hyge, situé dans les installations de l'institut Civile et de la Défense pour la Médecine de l'Environnement à Toronto. Les essais d'impact direct et indirect ont été effectués avec une décélération de 30g à partir de 48 km/h (30 miles à l'heure). Des mannequins anthropomorphiques à 5e percentile adulte du sexe féminin furent employés pour l'épreuve. Les mannequins instrumentés ont servi à cumuler les resultats reliés à l'accélération de la tête et de la poitrine, et à la charge sur le fémur et sur la ceinture de sécurité. Chaque essai effectué fut filmé à haute vitesse pour aider à l'analyse des données.

Chaque modification a presenté les resultats suivant:

1. Le rembourrage contournant le dossier du siège

Ce siège a obtenu essentiellement les même resultats que le siège standard.

2. Le siège avec dossier moins rigide

L'accélération maximale de la tête était sensiblement plus basse et l'accélération de la poitrine légèrement plus basse que celle du siège standard. La valeur du critère de blessure de la tête (HIC) était essentiellement la même que celle calculée pour le siège standard.

3. Le siège faisant face à l'arrière

Ce siège a présenté des améliorations significatives dans tous les domaines problèmatiques, comparé au siège standard.

4. Les systèmes de retenue avec trois attaches et attaches multiples

   Ces deux systèmes ont sensiblement réduit l'accélération de la tête et le critère de blessure de la tête, mais pas l'accélération de la poitrine.

Les conclusions suivantes peuvent être tirées de ce programme d'essai

1. Le siège faisant face à l'arrière s'est montré très efficace pour reduire tous les degrés de blessures à des valeurs acceptables.

2. La ceinture baudrier au système à trois attaches a diminué le critère de blessure de la tête (HIC) à un niveau acceptable mais n'a pas amelioré le niveau d'accélération de la poitrine. Cependant, si un système à trois attaches est installé dans un autobus scolaire, il faut absolument que l'occupant porte la ceinture à cause du renforcement considerable de la charpente du siège.

3. Les deux systèmes de sièges faisant face à l'avant et employant seulement les ceintures sous-abdominales ne se sont pas montrés efficaces pour diminuer le critère de blessure de la tête à une valeur acceptable.

4. Le système à attaches multiples était encombrant et a permis au mannequin de glisser sous le système de retenue.

5. Il faut reconsiderer le placement des rétracteurs sur la charpente inférieure du siège pour éviter le dommage possible causé par le contact des jambes de l'occupant en arrière.

6. L'augmentation de coût pour les trois systèmes munis de ceintures sous-abdominales est de moins de 60$ le siège. L'augmentation de coût pour les deux systèmes munis de ceintures sous-abdominales et de ceintures baudrier est de plus de 115$ le siège. Le cout des rétracteurs entraîne la plus grande augmentation de prix pour tous les systèmes.

BACKGROUND

In late 1984, Transport Canada performed full scale crash testing on three different sized school buses[1], to measure the effect that seat belts might have toward improving the occupant protection. The buses used were a 66 passenger, full size Blue Bird conventional type, a 22 passenger Thomas "Minotour" and a 20 passenger Campwagon van conversion. Each bus contained six 5th percentile adult female test dummies, instrumented to record forces on the head, chest and femurs. Three of these dummies were secured in place with a manually adjusted lap belt and three were left unrestrained. The buses were crashed into a concrete barrier at a speed of approximately 48 km/h (30 mph), to simulate a severe frontal collision.

For an analysis of the results, the Head Injury Criteria (HIC) value and resultant chest acceleration were used. The HIC value is a mathematical combination of resultant head acceleration and the duration of that acceleration. An upper limit of 1000 is used as the threshold above which serious injury or death can be inferred. An upper limit of 60 g for a duration greater than 3 milliseconds is the threshold used when determining the severity of the resultant chest acceleration.

In general, the results indicated that the belted dummies experienced higher head and lower chest accelerations than did the unbelted ones. Furthermore, from the film data, the belted dummies experienced more severe neck extensions, due to the angle at which they struck the seat ahead of them, than did the unbelted ones. Dummies restrained by seat belts in both the Thomas and the Campwagon buses experienced HIC values in excess of 1000, whereas the unrestrained dummies experienced HIC values of less than 1000. In the large Blue Bird bus, all dummies experienced HIC values of less than 1000 but the restrained ones experienced values approximately three times greater than those for the unrestrained ones.

These difference can be explained by the fact that the restrained dummies pivoted about the lap belt and struck their head very severely on the seat back in front. Sharp peaks in the head acceleration traces indicated that the dummy heads compressed the seat padding to such a degree that they "bottomed out" on the steel structure underlying the padding in the seat back.

These tests also indicated that if seat belts are to be added to school bus seats, the entire seating system had to be considered. Such consideration lead to the SCHOOL BUS SEAT DEVELOPMENT PROGRAM. Various seating concepts, incorporating restraint systems, were designed, built and tested. The object was to investigate methods of providing greater protection for occupants in all types of accident situations.

The results of the crash testing program are contained in Transport Canada report "SCHOOL BUS SAFETY STUDY"[1] Volumes I and II. The results of the "SCHOOL BUS SEAT DEVELOPMENT STUDY"[2] are contained in the Davis Engineering Report of the same title.

This report also contains the results of four supplementary sled tests performed on the school bus seats and expands somewhat upon the results detailed in the Davis report.

INTRODUCTION

The debate as to whether or not seat belts should be installed in school buses is not new, and a study of the issues involved indicates that there is no simple answer. Accident data illustrates that school buses are the safest form of surface transportation[3]. On average, fewer than two deaths per year occur to occupants of school buses. In fact, most deaths and injuries associated with school buses occur outside the bus.

There are several reasons which help to account for this excellent safety record. School buses travel at relatively low speeds between stops, at specific times of the day and on predetermined routes. They are a unique colour and employ special flashing lights to warn other motorists when they are stopped to load or unload students. In many provinces, stop arms are also employed as an additional warning to motorists. Provincial regulations make it an offense to pass a stopped school bus, with its warning lights activated while it is loading or unloading students. Most provinces also have special licencing provisions for school bus drivers.

There are also a number of safety features incorporated into the design and construction of school buses, to protect occupants in the event of an accident. Students are contained between high-backed, heavily padded, closely spaced seats. A high padded barrier is installed ahead of the front row of seats. Any structure located within a specified "HEAD PROTECTION ZONE" is padded or constructed to meet certain performance criteria.[4] These passive protective features are intended to keep the occupants in a relatively non aggressive environment in case of an accident. Side windows and windshields must pass specific performance tests.[5] Emergency exits must be provided and must be identified and tested to rigid performance criteria.[5] For large buses, the strength of the body joints is tested to very rigid specifications.[6] These buses must also have the fuel tank protected to prevent damage or leakage in case of an accident.[7] The roof of all school buses must be capable of supporting a load at least equal to 1-½ times the weight of the fully loaded bus[8], ensuring that the roof will not collapse if the bus rolls over. The seats themselves are subjected to deflection tests to ensure that the mounting to the floor is adequate and that the back can absorb a specified amount of energy if it is struck by an occupant.[4]

Most provinces in Canada have mandated the use of seat belts in vehicles if they are installed as standard equipment by the manufacturer. Many people therefore question why such belts are not mandatory in school buses.

The crash tests performed in 1984 showed that the use of a lap belt alone could result in more severe head injuries to belted occupants than to unbelted ones -- for head-on collisions. They also showed that the level of head injury experienced by both belted and unbelted dummies in the large bus was well below the level that is considered dangerous. These tests did not measure the effect belts might have in protecting occupants during side collisions or rollover type accidents. In these types of accidents, a seat belt would aid in preventing possible ejection and being thrown around the interior of the vehicle.

As a result of the crash tests, the need to investigate the entire seating system became apparent. It was not just a simple matter of adding a lap belt to a seat.

The seat development project involved the design, construction and testing of five different seating concepts, each employing a restraint system. The seats were tested on the Hyge sled (photograph #1) located at the Defence and Civil Institute for Environmental Medicine (DCIEM) in Downsview, Ontario. Each seat was tested to simulate a 48 km/h (30 mph) head-on collision and a 48 km/h (30 mph) collision at an angle of 30 degrees from the head-on direction. The tests were conducted with an acceleration input of 30 g. These test parameters are somewhat less severe than the Campwagon van tested in 1984 (47.1 km/h, 49.0 g) and somewhat more severe than the Thomas Minotour (47.0 km/h, 19.5 g) and much more severe than the Blue Bird bus (48.8 km/h, 15.0 g).

No direct comparison is made between these tests and the barrier crash tests due to the differences in the crash pulses and the test protocol. These results would lie somewhere between those of the Thomas "Minotour" and the Campwagon van barrier collision tests.

These tests were performed to provide additional information that can be used to develop systems which will improve the protection provided for occupants of school buses. The results indicate that if restraint systems are installed, some configurations perform better than others. The results are intended to provide seating system designs and concepts for jurisdictions who wish to enhance the excellent protection already provided to occupants of school buses.

APPROACH

In this project, five different types of seating systems were designed, fabricated and tested. These were as follows:

i) contoured padded seat back and lap belt
ii) less aggressive seat back and lap belt
iii) rearward facing seat with lap belts
iv) three point restraint system, and
v) multi-point restraint system.

The design parameters for these seating systems included the following:

1. Design to be based as much as possible on existing seats.

2. Restraint system to incorporate emergency locking retractors.

3. Belts to be attached to the seat structure.

4. Seats to be easily manufacturable.

5. Ingress and egress for students to be as easy as possible.

6. The seats must accommodate students ranging from a 6 year old child to a 50th percentile adult male.

7. Systems to comply with existing CMVSS regulations 208, 209, 210 and 222 if possible.

The reference seat was a Bluebird 0.99 m (39 in.) seat (photograph #2) which currently meets CMVSS 222 "School Bus Passenger Seating and Crash Protection". This seat has a reinforced lower frame to accommodate lap belts, and satisfies the strength requirements of CMVSS 210, "Seat Belt Assembly Anchorages". All configurations are modifications of the Blue Bird seat.

Dynamic sled Testing of Seats

Two tests were performed for each of the five types of seats and an unmodified seat, for a total of twelve test runs. The first set of tests simulated a head on collision with a peak acceleration of 30 g and a maximum velocity of 48 km/h (30 mph). The second set of tests

simulated an oblique collision where the direction of acceleration was 30° from the vehicle longitudinal axis. The peak acceleration was also 30 g and the maximum velocity was 48 km/h (30 mph).

In addition to these twelve tests, four runs were made to simulate various other crash situations. The peak acceleration and velocity change were the same. The description and results of these tests are described in the section entitled "Supplementary Tests".

Testing Facility and Instrumentation

The tests were carried out at the Impact Studies Facility at DCIEM in Toronto (photograph # 1). Vehicle impacts are simulated in the "reverse mode" at this facility, i.e. the test sled is accelerated backwards at a predetermined rate from an initial rest position. The basic components of the impact simulator are a Hyge hydraulic/pneumatic actuator and a test sled/rail system.

Two 5th percentile adult female anthropomorphic test devices (ATDS) were used in the tests. The rear ATD was instrumented with triaxial accelerometers in the head and chest, and with force transducers in the left and right femurs. Seat belt load transducers were used on each seat and shoulder belt as required. The front ATD was not instrumented, but was used for loading purposes only.

Four on-board high speed cameras were used during the tests, one on either side, one in the front, and one to the rear. Two off-board sequence cameras, which use polaroid film, were also used to provides eight sequenced still pictures of the impact.

Pretest Setup

Each test employed two seats and two ATDs unless noted otherwise. The seats were mounted to a 37 mm (1½ in.) thick plywood board, which was mounted to the steel frame of the test sled. The seat spacing used for each test was approximately 660 mm (26 in.) from the rear surface of the front seat back to the front surface of the rear seat back. This is approximately equivalent to a distance of 533 mm (21 in.) from the rear seating reference point (SRP) to the back surface of the front seat back. The distance was determined by measuring horizontally forward from the hip pivot point of the ATD placed on the rear seat.

The ATD was placed at the rear seat centre seating position and rocked slightly to settle into the seat. The lap belt was buckled. Since Emergency Locking Retractors (ELR) were used on all restraint systems except the multi-point and unmodified seat, the retractive force of the retractors held the belts against the ATD with no slack.

For the unmodified seat, which employed manually adjustable lap belts, the belt was buckled and adjusted to a snug fit around the ATD pelvis, with no slack (photograph # 13). The same procedure was used for the multi-point system. After the lap belt was buckled, the upper torso straps were adjusted manually to remove all slack from the restraint system.

The face and knees of the rear ATD were covered with a chalk coated cloth, as a means of marking impact areas between the ATD and the front seat. The rear of the front seat was painted white before each test.

The position of the top of each seatback, relative to a fixed point on the sled frame, was measured to determine if any permanent deformation of the seat back occurred during the impact test.

RESULTS

Preamble

The Head Injury Criteria (HIC) is defined in the current Canadian Motor Vehicle Safety Regulations as

$$HIC = \left(\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a\,dt \right)^{2.5} (t_2 - t_1)$$

where "a" is the axial acceleration of the centre of gravity of the head, expressed as a multiple of "g" (the acceleration due to gravity),

"t_1" and "t2" are any two points in time during impact

If the value of this expression exceeds 1000, it is assumed that the forces on the head would be severe enough to cause serious, life-threatening injury or death.

Although the HIC has some limitations, it is a common automotive testing measure for determining the possible severity of head injuries. It also provides a value for comparing the relative severity of several identical tests. HIC in the form currently used worldwide in automotive testing provides an indication of a certain level of injury to the head and it is included here.

The chest accelerations are also included. If the resultant chest acceleration exceeds 60 g for a period of time greater than 3 milliseconds, serious injury to the occupant will probably occur. It is probable that a child's tolerance to chest injury as a result of an impact would exceed that for adults due to the greater elasticity of a child's bone structure.

It seems reasonable to assume that the injury criterion commonly used for adults (HIC and chest acceleration) give some relative indication of injury potential for children but the limits are suspect. In the absence of better measures these values are used here, as they were in the previous crash test study.

The fifth percentile adult female dummies were used so that some comparison could be made between these tests and the barrier crash tests performed in 1984[1]. Since the ATD's are not constructed to record forces on the neck, any comments concerning neck bending or injury are subjective and resulted from viewing the high speed films.

It is recognized that the neck and torso of the ATD are stiffer than in a human subject. This stiffness could induce greater head velocity by the time the head strikes the seat back in front and thus result in a higher indication of injury than would occur in a "real life" accident. It also prevents the spine from flexing and possibly allowing the shoulders to contact the seat back and absorb some of the energy of the collision. However, it is felt that these results provide a reliable comparison of the relative performance of each seat system tested.

The following sections summarize the test results and observations of the five seating systems studied in this project.

FORWARD FACING SEATS WITH LAP BELTS ONLY

GENERAL

The contoured padded seat back and less aggressive seat back come under this configuration. The specific objective of these designs was to reduce the deceleration spike and Head Injury Criteria (HIC) value experienced by the test dummy during a frontal collision by a factor of two, when compared to the unmodified seat results. A secondary consideration was to reduce the rearward rotation of the head, and thus lessen possible neck injury.

The Transport Canada report entitled "School Bus Safety Study"[1] along with its associated film documentation showed that the ATD's secured with lap belts pivoted about the lap belt and produced head impacts more severe than unbelted ATDs. The head struck the top of the seat back in a downward direction of 30 to 45 degrees to the horizontal. The high peak head accelerations recorded during the collision tests were due to the stiffness of the seat back, for downward impacts. The relatively thin padding in this area resulted in the head of the dummy effectively bottoming out on the underlying frame structure.

The existing Blue Bird bus seat has a reinforced lower frame to accommodate lap belts. The seat cross member was modified by adding an extra horizontal tubular member to increase the mounting area for the seat belt retractors (photograph #3). The seat belts were located so as to conform to the requirements of CMVSS 208 "Seat Belt Installations" and 210 "Seat Belt Assembly Anchorages". The angle of the line joining the seating reference point to the

seat belt mounting location was approximately 60°, to lessen any possibility of submarining.

Contoured Padded Seat Back

The intent of this design was to increase the thickness of energy absorbing foam in the head impact area, in order to reduce the severity of any head contact.

An earlier study conducted for Transport Canada[9], tested seats with a variety of padding configurations and thicknesses. Based on this testing, a 100 mm thickness was selected. This additional padding does not present any obstruction to occupant knees or restrict entry to or exit from the seat.

To provide a more controlled deceleration of the head, two foam densities were used. A denser, high energy absorbing foam was used around the seat frame and a less dense foam was used between the inner foam and the seat back upholstery. The extra foam thickness is localized to the area of impact at the top of the seat and extends part way down the back of the seat (photograph #4). The contoured seat back padding was designed to slip over existing unmodified seat frames. This would ensure potentially low cost modification for the manufacture of buses as well as an inexpensive retrofit for buses in service.

Contoured Padded Seat Back - Results

Tabulation of results is given in Tables 2, 3, 4 and 5. The tests on the unaltered seats were performed to provide baseline data to which other seats can be compared. The unaltered seat (photos 14, 15 and 16) resulted in a HIC value of 1116.6 and a resultant peak chest acceleration of 58.9 g for the head-on test. The results for the contoured padded head-on test (photos 17 and 18) did not show any improvement in performance, when HIC values are compared (1082.0). The resultant peak chest acceleration for this seat was 71.6 g. The threshold value of 60 g was exceeded for more than 3 milliseconds as well. This result is actually a degradation in performance as compared to the unaltered seat. The reason for the high chest acceleration is not known.

The addition of the foam padding to the contoured padded seat was expected to significantly reduce the peak head acceleration. This was not the case for the head-on test because the energy absorbed by the additional foam was

a much smaller percentage of the total transmitted energy than was originally expected. In fact, if we assume that the total transmitted energy is equivalent to the kinetic energy of a mass equal to 40% of total body weight (i.e. the estimated weight of the upper torso) moving at 48 km/h (30 mph) the percentage of energy absorbed by the foam is in the order of 1%.

For the oblique impact, the contoured padded seat showed a significant decrease in peak head acceleration (see Table 2). The reason for this can be found in the angle and area of head impact (photograph #19, 20, 21). The point of head impact was in the upper corner of the seat back rather than the centre as in the head-on case. Also the angle of head impact is approximately 60° to the seat back, resulting in a glancing blow only. For the contoured padded seat, the head contacted the additional foam only and not the underlying seat frame. For the unaltered seat (photographs #22, 23), there is much less padding and therefore the area of contact is much more rigid. Even though head accelerations were much lower for the oblique impact on the contoured padded seat than for the unaltered seat, there is almost no change in the HIC value between these two cases. The resultant acceleration curves are basically the same, except the spike in the unaltered seat curve is not present in the contoured padded seat curve. This implies that the acceleration spike contributes very little to the calculated HIC value.

If the HIC value is used to assess the effectiveness of a given seat we arrive at the conclusion that the contoured padded seat offers no improvement over the unaltered seat for both head-on and oblique cases. This seems reasonable for the head on case since peak resultant head accelerations are not the same for both cases, but must be questioned for the oblique case, since the contoured padded seat produces a peak acceleration which is only 40% of the peak acceleration for the unaltered seat.

It should be pointed out that the HIC value does not take into account a variety of factors such as neck extension which are difficult to quantify. The test films show that the contoured padded seat reduces neck extension noticeably, yet this fact is not accounted for when the seats are evaluated solely on the basis of HIC value.

The femur loads shown in Table 4, are significantly lower for the unaltered seat. This is likely due to the fact that manually adjusted belts are used on the unaltered seat while retractors are used on the contoured

padded seat. The retractors allow the belt webbing to spool-out slightly before becoming taut, thus allowing the knees to contact the seat in front.

A problem which became evident in this test was the location of the seat belt retractors. The rear ATD's right leg hit the centre retractor, destroying the casing and allowing the front belt webbing to spool out (Photographs #39, 17, 25). It will be necessary to add protective shielding to the retractors to prevent their destruction in an accident.

Less Aggressive Seat Back

The intent of this design was to allow the top portion of the seat back structure to deform upon impact and thereby absorb sufficient energy to reduce the head acceleration.

The structure was modified by replacing the channel member which runs along the top of the seat back and part way down the sides, with a smaller 12 mm outer diameter 1.5 mm wall thickness round tube (photograph #5 & 6). Under loading from the rear, the top portion of the seat back was designed to deflect forward at a force level below that which causes the unmodified seat back to deform, yet above that which would allow occupants to damage the seat during its normal operation.

Less Aggressive Seat Back - Results

The less aggressive seat (photographs #24, 25, 26), showed no improvement in the HIC value when compared with the unmodified seat (1079.8 vs 1116.6, see Table 2). Although the HIC value was not lowered for the less aggressive seat, the peak accleration did decrease by approximately 40% for both impact cases. The acceleration vs. time curve is essentially the same as that for the unaltered seat, except that the large acceleration spike has been eliminated. This seat has performed as expected, in that it has significantly reduced the peak head acceleration. Unfortunately it did not reduce the HIC value as much as was anticipated. This seems to be due to the fact that, even though the energy is absorbed over a larger period of time, the amount of energy that must be absorbed by the head is basically unchanged.

The permanent deformation to the upper seat back frame member (photograph # 27) of the less aggressive seat was approximately twice as much as to the unaltered seat

(see Table 5). This also tends to confirm that this seat performed as was anticipated.

The less aggressive seat had a positive effect on chest acceleration, reducing the resultant peak acceleration by approximately 18% for both impact cases. The peak acceleration for the head on case was less than 60 g. For the 30° oblique impact, the peak acceleration exceeded 60 g, but the duration was less than 3 milliseconds.

For this restraint system, deformation to the seat back was the result of head contact. There was minimal deformation to the seat legs. The femur loads were approximately the same as those recorded for the contoured padded seat, much higher than recorded for the unaltered seat. These higher values can again be attributed to belt spool out from the retractors.

The destruction of the retractor, as noted for the contoured padded seat, was also evident during the testing of this seat design.

SEATS WITH LAP AND SHOULDER BELTS

GENERAL

The Three-Point Restraint System and Multi-Point Restraint System came under this configuration. The design of a school bus seat to accommodate lap and shoulder belts involved a change in design philosophy.

The Canadian Motor Vehicle Safety Standard (CMVSS) 222 requires that the seat back be sufficiently flexible to absorb a specified amount of energy, when subjected to a specified force. However, a seat with lap and shoulder belts must be designed to withstand much higher loads with no structural separation of the seat structure or anchorages. It is therefore impossible for a seat with shoulder belts to satisfy both CMVSS 222 and CMVSS 210 (Seat Belt Assembly Anchorages). Both the three point and multi-point restraint systems were designed using the same basic seat structure.

It must be emphasized that if seats with lap and shoulder belts are installed in buses, it is imperative that the belts be worn at all times. Otherwise, any injuries due to unrestrained occupants striking the seat back would be more severe than with an existing seat due to the increased seat rigidity.

Three-Point Restraint System

CMVSS 210 requires that seat belt loads of 13350 N (3000 lb) be applied to the lap belt at an angle of 10 degrees above the horizontal and, 13350 N (3000 lb) to the shoulder belt at a height mid-way between the lap belt and shoulder belt attachment points at an angle of 10 degrees to the horizontal.

A finite element modelling approach was used to simulate design alternatives, using the existing Blue Bird seat as a starting point. It was found necessary to add a centre leg, to increase the stiffness of the seatback and to add diagonal braces to the legs (photograph #7 & 8). The additional members are identical to the square tubing used in the existing seat.

The system was designed to accommodate occupants ranging in size from a 50th percentile 6 year old child to a 50th percentile adult male. The lap belt portion of the system was configured in the same way as the lap belt systems previously described. For the upper torso portion, which incorporates an emergency locking retractor, the belt webbing enters the seat padding material at the top of the seat structure, goes through a D-ring guide attached to the seat back frame and down to the retractor attached to the seat base frame (photographs 7 and 8). Operation of the system is the same as for a front outboard position on a passenger car.

Multi-Point Restraint System

The multi-point restraint system also accommodates three small occupants per seat, and is the only system which does not utilize retractors (photograph # 9). The belt configuration was based upon Barwick Industries Model 2200 system and uses four anchorage locations per belt system.

The structural frame is the same as that for the three-point restraint system except that the seat back is somewhat wider at the top to accommodate the increased space required between the shoulder belt anchorages (photograph # 10). The same lap belt anchorage points were used. Adjustment is made via two adjusters located on the upper torso section of the belts.

Seats with Lap and Shoulder Belts - Results

The three-point (photographs #31, 32, 33) and multi-point (photographs #35, 36, 37) restraint systems

produced similar results. In both cases there was no head contact with the seat back in front (photographs#34, 38). Also, the peak head accelerations in both cases did not occur in the initial impact but rather occurred during sled braking as the ATD's head hit the seat back of its own seat. Even though this secondary impact caused the highest peak acceleration it was of a very short duration and was not significant in the calculation of the HIC value. The maximum HIC value for the three point seat and multi-point seat was less than 1000 for both the head on and oblique impact cases. (See Table 2.)

The chest acceleration exceeded 60 g during all tests of these restraints. For the three point restraint, the duration was less than 3 milliseconds for the head on impact. However, the 60 g limit was exceeded for more than 3 milliseconds during the 30° oblique impact. For the multi-point system, the duration exceeded 3 milliseconds in both cases.

Because the upper torso is restrained in these designs, submarining became a concern. No submarining was evident in the case of the three-point restraint system in either impact case. For the multi-point restraint system, however, the front ATD* submarined during the head on impact (photograph #37). Both ATDs exhibited submarining during the oblique impact.

The deflection of the seat back was slightly greater for the multi-point system than for the three point (see Table 5), since the multi-point seats have more load transmitted to the frame through the shoulder belts. There was no deformation in the frame legs.

Both the three point system and multi-point system resulted in large femur loads for the ATD's. In the case of the three point restraint, this is probably due to spool out of the belt webbing from the retractor, thus allowing more forward knee excursion. For the multi-point restraint, which did not employ retractors, the high femur loads were probably a result of the submarining that was observed.

---

* It should be noted that the arms on the front ATD were tied to the body during testing. Submarining may not have been as severe if they had been allowed to swing freely. Nevertheless this is considered a major concern with this design.

THE REARWARD FACING SEAT

The rearward facing seat was used in conjunction with the same lap belt system used on the contoured padded and less aggressive seating systems. The seat back frame was 250 mm higher than the existing standard seat (photograph # 11) and was contoured slightly forward at the top to increase occupant comfort and provide a head restraint for a 50th percentile adult male (photograph #12). The cushion thickness on the occupant side of the seat back was increased to 50 mm from 32 mm.

The frame itself was modified from the existing Blue Bird seat only to increase the height of the back. The same square tubing was used in the modification. Due to the increased height of the seat back, a horizontal flat bar member was added to provide additional support.

Rearward Facing Seat - Results

This seat was installed on the test sled to simulate a rearward facing direction in a bus. This seat (photograph #28) yielded the best results of all configurations. The resulting HIC values were very low, (approximately 300) (Table 2). Although there was some head contact with the seat in front of the ATD, this impact was of very small magnitude and occurred only on rebound (Photograph #30). The chest accelerations for the rearward facing seat were well below the 60 g limit (approximately 35 g) for both impact cases. As with the HIC values, this seat configuration produced the lowest chest accelerations of all seats.

The seat back rotated about its base approximately 20° in both tests, due to the fact that all of the load imposed by the occupant was transmitted directly to the back (photograph 29). There was very little deformation in the seat legs.

SEAT SERIES	HEAD ON IMPACT		30° OBLIQUE IMPACT	
	Max. Velocity (MPH)	Max. Accel. (g)	Max. Velocity (MPH)	Max. Accel. (g)
Unaltered	29.3	32.1	30.1	30.9
Contoured Padded	30.0	31.2	30.7	31.7
Less Aggressive	29.8	30.8	30.2	30.7
Rearward Facing	30.1	31.2	30.4	30.2
Three point	29.1	30.4	29.5	31.5
Multi point	29.9	31.2	29.5	31.6

TABLE 1: PEAK SLED VELOCITY AND ACCELERATION

SEAT SERIES	HEAD ON IMPACT			OBLIQUE IMPACT		
	Resultant Peak Head Accel (g)	HIC	Resultant Peak Chest Accel (g)	Resultant Peak Head Accel (g)	HIC	Resultant Peak Chest Accel.(g)
Unaltered	199.8	1116.6	58.9	227.6	1181.4	79.8
Contoured Padded	200.4	1082.0	71.6**	92.1	1154.9	68.2
Less Aggressive	114.9	1079.8	48.6	145.4	1423.8	65.0
Rearward Facing	59.1	275.6	35.1	58.8	309.2	35.4
Three point	58.2*	634.0	60.3	88.5*	917.6	72.2**
Multi point	184.3*	558.8	65.3**	217.7*	834.5	68.7**

Note: * Peak accleration occurs in secondary impact.
** Value exceeded 60 g for more than 3 milliseconds.

TABLE 2: HEAD AND CHEST ACCELERATIONS AND HIC VALUE

SEAT SERIES	MAXIMUM BELT LOADS (lbs)							
	HEAD ON IMPACT				30° OBLIQUE IMPACT			
	Left Lap	Right Lap	Left Shoulder	Right Shoulder	Left Lap	Right Lap	Left Shoulder	Right Shoulder
Unaltered	1967	1953	-	-	2070	2221	-	-
Contoured Padded	2126	1396	-	-	2608	1838	-	-
Less Aggressive	1505	1509	-	-	2030	1626	-	-
Rearward Facing	85	76	-	-	116	142	-	-
Three-Point	1930	1324	-	1147	2257	1278	-	N/A
Multi-Point	1373	1669	724	840	1534	1730	816	1163

TABLE 3: MAXIMUM SEAT BELT LOADS

SEAT SERIES	HEAD ON IMPACT		30° OBLIQUE IMPACT	
	Left Femur Load (lbs)	Right Femur Load (lbs)	Left Femur Load (lbs)	Right Femur Load (lbs)
Unaltered	397	334	313	588
Contoured Padded	714	1555	839	708
Less Aggressive	694	1685	869	499
Rearward Facing	518	522	313	391
Three Point	2350	1456	1389	346
Multi Point	2224	2181	1667	508

TABLE 4: MAXIMUM FEMUR LOADS

SEAT SERIES	DEFLECTION AT TOP CENTRE OF SEAT BACK (in)			
	HEAD ON IMPACT		30° OBLIQUE IMPACT	
	Front Seat	Rear Seat	Front Seat	Rear Seat
Unaltered	2.9	0.4	1.2	0
Contoured Padded	N/A	N/A	1.5	0.3
Less Aggressive	5.7	0.3	2.0	0.3
Rearward Facing	9.6	11.9	10.5	-
Three Point	N/A	N/A	0.6	0.4
Multi Point	4.9	2.3	3.4	2.2

TABLE 5: APPROXIMATE DEFLECTIONS AT TOP CENTRE OF SEAT BACK

COSTS

In order to estimate the cost to incorporate each design into a school bus, information was obtained from the Blue Bird Body Company in Fort Valley, Georgia. The estimated increase in cost to build a seat which incorporates the changes is tabulated in Table 7. All figures are in Canadian dollars, using a 40% exchange rate when converting from the U.S. dollar values provided by Blue Bird.

These figures do not include any provisions for modifications which could be required to the bus body. For restraint systems employing only lap belts, such modifications should not be required. For the three-point and multi-point, the floor of the vehicle will have to be analysed further to ensure that it can withstand the increased loads.

These cost figures also do not include any provision for modifications which must be made to the seats as a result of the testing. The retractor, located at knee level, will have to be protected from damage. The rearward facing seat should be reinforced somewhat to lessen the deflection. Such costs would depend upon the final design chosen.

These designs and costs are based on a specific manufacturers seat. Other manufacturers would have to modify the designs to suit their own manufacturing methods.

Seat Type	(1) Cost of Frame Modifications Per Seat	(2) Cost of Restraint System Per Seat	(3) Total Cost Increase Per Seat	Total Cost Per 66 Passenger Bus	Total Cost Per 22 Passenger Bus
Contoured padded	$7.00	$33.00	$40.00	$880.00	$320.00
Less aggressive	$20.30	$33.00	$53.30	$1172.60	$426.40
Rearward facing	$26.60	$33.00	$59.60	$1311.20	$476.80
Three-point	$63.70	$52.50	$116.20	$2556.40	$929.60
Multi-point	$109.20	$45.00	$154.20	$3392.40	$1233.60

TABLE 6: PRODUCTION COST INCREASE ESTIMATES

(1) These figures are increased costs for changes made to basic Blue Bird seat. These are Blue Bird's wholesale price to their distributors and do not include a distributor mark-up.

(2) These costs are actual costs for standard items from Bendix Restraint Systems. These retractors are stock items and there is no discount for volume quantities.

(3) This would be wholesale cost to school bus distributor.

SUPPLEMENTARY TESTS

I FRONTAL- UNBELTED ATD - CONTOURED-PADDED SEAT

The purpose of this test was to measure the effect that the contoured padded seat back would have on an unrestrainted occupant during a frontal collision. The instrumented ATD was placed at the centre seating position on the rear seat and was left unbelted. The front seat was a contoured-padded type. The front seat contained an uninstrumented ATD that was secured in place at the centre seating position by the lap belt (photograph #51). The test was performed at 49.4 km/h (30.9 mph) change in velocity and 31.5 g acceleration.

During the test, the rear ATD slid forward on the seat until the knees made contact with the seat in front (photographs # 52, 53). This contact caused the ATD to pivot about the hips and strike its head on the top rear edge of the seat, about chin level. The ATD started to "stand up" and the chest made contact with the seat back. The head of the ATD bent forward over the seat back approximately 45 degrees. On rebound, the ATD was approximately 380-500 mm (15"-20") above the seat cushion and it settled into its original seating position. The knee contact with the seat in front broke the retractor (photograph #54), which allowed the front seat belt webbing to spool out to its full length.

The test results are tabulated in Table 7. The HIC calculated for this test was 581.6, well below the threshold value of 1000.

The corresponding test using a belted ATD on the rear seat resulted in a HIC value of 1082.0. The peak head resultant acceleration for the belted ATD was 200.4 g compared to 115.4 for the unbelted one.

The resultant peak chest acceleration for the unbelted ATD was 66.1 g. The threshold value of 60 g was exceeded in this case for approximately 7½ milliseconds. For the equivalent test using a belted ATD on the rear seat, the peak chest acceleration was 71.6. However, the value of 60 g was not exceeded for more than 3 milliseconds.

These results show that for an unbelted dummy hitting the contour padded seat, HIC values are reduced considerably when compared to a belted dummy. However, chest acceleration for the unbelted ATD exceeds the limit by a large margin.

II FRONTAL - LESS AGGRESSIVE SEAT

This test was conducted to determine whether or not greater injuries would result if the occupant contacted the corner of the less aggressive seat back, rather the centre. An instrumented ATD was placed at the aisle side seating position on the rear seat (photograph #55), and was secured in place with the lap belt. An uninstrumented ATD was placed at the centre seating position of the front seat and was also secured in place with the lap belt. The front seat was an unused Less Aggressive type. The test was performed at 48.6 km/h (30.4 mph) change in velocity and 30.8 g acceleration.

During the test, the ATD slid forward approximately 380 mm (15") before the seat belt "locked up". The knees of the ATD made severe contact with the seat in front before the belt was tight, causing the seat back to deflect forward before the head made contact. The head of the ATD hit the corner of the seat in front at about eye level and the neck experienced rearward bending of approximately 90 degrees. There was considerable deformation of the seat back (photograph #56). The test results are tabulated in Table 7.

The resultant head acceleration curve is virtually identical to the one generated during the frontal test for this seat design, with the ATD at the centre seating position, except that the peak is higher (166.9 g vs 114.3 g) and the HIC value is considerably higher (1670.5 vs 1079.8). This would indicate that the corner is stiffer than the centre portion of the seat frame, as expected.

During this test, the front seat belt broke. It appeared that this was caused by the plastic housing used to keep the belt at seat level. This was the only test during which a belt broke and it is therefore considered an isolated incident. It does, however, show the importance of properly designing the surfaces against which the belt will bear during a collision.

III FRONTAL - THREE POINT SYSTEM - TWO ATD'S ON SEAT

The purpose of this test was to determine whether or not the seat was strong enough to withstand loading from two occupants. An unused seat, incorporating the three-point restraint system was used for this test. Two

ATD's were placed on the rear seat, at the outboard seating positions (photograph #57). The ATD at the window side was instrumented while the other was not. Due to previous damage to the uninstrumented ATD, its arms were strapped to the upper torso with seat belt webbing material and the head was strapped in its lap (photograph # 58). Both ATD's were secured in place with the three-point belt system. The front seat was an unused seat with a multi-point restraint system. There was no ATD on the front seat. This test was performed at 47.2 km/h (29.5 mph) change in velocity and 31.0 g acceleration.

During the collision, both ATD's made knee contact with the seat in front, probably due in part to webbing spool out and partly due to increased deflection of the seat back. There was no facial contact with the front seat. The neck of the instrumented ATD flexed forward approximately 90 degrees allowing the top of the head to contact the seat in front (photograph #59). Both ATD's rebounded into their initial seating position. Test results are tabulated in Table 7.

For this test, the maximum resultant head acceleration was 215 g with a HIC value of 1316.9. The results for the test with a single ATD at the centre seating position were 58.2 g maximum resultant head acceleration and 634.0 for HIC. These differences point out the importance of eliminating head contact in order to lower the HIC value to an acceptable level. Chest accelerations in both cases were below the threshold value.

IV FRONTAL - REARWARD FACING SEAT - THREE ATD'S ON SEAT

The purpose of this test was to determine the performance of the high backed, rearward facing seat when three occupants were seated on the seat. This seat was oriented to simulate a rearward facing direction in the school bus. Only one seat was used for this test due to space limitations on the test platform. The seat was an unused rearward facing one, employing lap belts. Two 5th percentile adult female ATD's and one 5th percentile six year old child ATD were used (photograph #60). Only one of the adult ATD's was instrumented. The other adult ATD was damaged and the head and arms were secured as described in the test employing the two ATDs with the three point restraint system. This test was performed at 49.4 km/h (30.9 mph) change in velocity and 31.0 g acceleration.

During this test, the sidewall support for the seat failed (photographs # 61, 62), allowing the seat to deflect rearward more than it would have normally. At the conclusion of the test, the seat had deflected to approximately 15 degrees above horizontal (photograph #63). The legs of the ATDs were flung upward since there was no seat in front of the test seat. Had a seat been in front, the lower legs of the ATDs would have struck it fairly hard. The test results are tabulated in Table 7.

The much lower resultant chest acceleration for this test employing a single ATD, when compared to the head-on test, (23.8 g vs 35.1 g) could be a result of the failure of the seat mounting pedestal.

DESCRIPTION	MAX HEAD ACCEL(g)	HIC	MAX CHEST ACCEL(g)	LEFT FEMUR (lbs)	RIGHT FEMUR (lbs)	LEFT (#1) LAP BELT (lbs)	RIGHT (#2) LAP BELT (lbs)	SHOULDER BELT (lbs)	COMMENTS
Padded Contoured Unbelted Dummy	115.4	581.6	66.1	1588.9	1693.8	-	-	-	Chest exceeds 60 g for 8 msecs. 31.5 g 49.4 km/h
Less Aggressive Dummy at Aisle Belted in Position	166.9	1670.5	Lost Data	1314.2	1567.1	1220.2	1303.5	-	Front lap belt broke during test. 30.8 g 48.6 km/h
	Head acceleration resultant curve is virtually identical to less aggressive except that peak is 166.9 instead of 114.3								
Three-Point Two Dummies On Seat	215 (est.)	1316.9	61.1	2079.2	1535.0	1181.1	1365.9	935.2	Both ATD 5% female RH ATD head hit timing box on re-bound - ignore this spike on data. 31.0 g 47.2 km/h
	Head acceleration much higher than frontal with one ATD on seat. Chest about same. HIC much higher.								
Rear Facing 3 Dummies On Seat 2x5% Female 1x6 yr. old	Lost Data	Lost Data	23.8	181.4	247.0	157.6	-3.35	-	49.4 km/h 31.0 g
	Chest was 35.1 on other test with one ATD. Lower result could be result of side support breaking.								

TABLE 7: SUPPLEMENTARY SLED TEST RESULTS

MISCELLANEOUS

When considering whether or not to install seat belts in a school bus, several ancillary items must also be taken into account. If a three-point system is used, the modifications to the seat structure make the seat very rigid in comparison to the existing seat. It may also be necessary to reinforce the floor in order to accommodate the increased loads during an accident. The stiffer seat back makes it imperative that each occupant wear the restraint system properly at all times. Otherwise, contact could be made with a very rigid structure during an accident.

The incorporation of restraint systems would mean that a seating position with a properly operating restraint system would have to be provided for each student. In many instances, this could mean that additional buses or bus routes would be required in order to accommodate all the students.

The responsibility for ensuring that all occupants correctly wear their restraint would have to be established. All Canadian provinces have or are introducing belt use laws. In most of these provinces, it is an offence to drive a motor vehicle which has seat belts installed at the passenger seating positions unless any occupant seated at such a position is wearing the belt and the belt is properly adjusted. This applies if the occupant is less than 16 years of age in most provinces (18 in Manitoba). This places the onus on the driver to ensure that each student under the age limit is seated and properly restrained before the bus is driven. The method of ensuring compliance with these laws presents some operational problems.

RETRACTORS

Careful consideration of the various types of locking retractors should be undertaken before a decision on

a particular type is made. It is felt that manual belts are too prone to being improperly adjusted to be considered for use.

Emergency Locking Retractors (ELR) were specified to optimize the comfort and convenience of using the belts. The ELR was specified to eliminate any "cinch down" problems that might occur with an automatic locking retractor during vehicle motion. Cinch down occurs when an automatic locking retractor tightens the belt around the occupant as a result of vehicle movement. The amount of cinch down would be dependant upon the amount of belt that would have to be retracted in order for the retractor to tighten up another notch on the ratchet.

Table 4 gives the values of the forces recorded on the femurs of the ATD. For the unaltered seat, which employed manually adjusted lap belts, femur loads were very low, which would indicate that the ATD slid very little on the seat before the lap belt started restraining it. The full scale crash testing performed in 1984 employed manual belts, similar to the unaltered seat tested here, for all belted dummies. The femur loads for all cases were very low. The higher relative value recorded in this test program could therefore be partially attributed to spool-out of the webbing and to the slight delay between the onset of the force and lock-up of the retractor.

The femur loads for all tests were below the acceptable limit of 2250 pounds except for the left femur of the three point system. This could be a result of the increased stiffness of the back of the seat in front.

The slow motion films showed that the ATD slid on the seat cushion before the retractor locked-up. In many cases, the retractors were broken by the rear ATD's leg, allowing the belt in front to spool out, obviating any protection to the occupant of that seating position.

If the cinch down problem can be overcome, there is no technical reason why an automatic locking retractor (ALR) could not be used. It is felt that either the ELR or

ALR is required on a lap belt system in order to be more comfortable for the user and to optimize the chances of the belts being used. For the three-point system, an ELR would be required in order to allow some freedom of upper body movement.

CONCLUSIONS

The following conclusions can be drawn from this test program:

1. The rearward facing seat was effective in reducing all injury levels to acceptable values.

2. The upper torso restraint on the three-point system reduced the head injury (HIC) value to acceptable levels but did not improve the resultant peak chest acceleration. However, if a three-point restraint system is used, it is imperative that the occupant wear the belts due to the increased stiffness of the seat structure.

3. The two systems which used modified forward facing seats and lap belts only were not effective in reducing the head injury criteria (HIC) to acceptable levels.

4. The multi-point seat belt system was cumbersome to use and permitted submarining of the test ATD.

5. The location of the retractors on the lower seat frame must be re-examined to prevent possible damage by leg contact from the rear.

6. The modifications for the three systems which employ lap belts only cost below $60 per seat. The modifications for the two systems which incorporate upper torso restraint cost in excess of $115 per seat. Retractors represent the most significant increase in cost for all systems.

RECOMMENDATIONS

The following recommendations are made based on the results of the testing performed in this project.

1) The rear facing seat system should be the subject of further investigation and testing. The seat back should be made stiffer to decrease deflection due to occupant loading. Consideration should be given to a demonstration project with a bus with rear facing seats to investigate possible field operational problems and the acceptance of such seats by students. In addition, consideration should be given to modifying CMVSS 222 to allow rearward facing seats, since only forward facing ones are permitted at this time.

2) The retractors should be protected to prevent destruction under impact conditions.

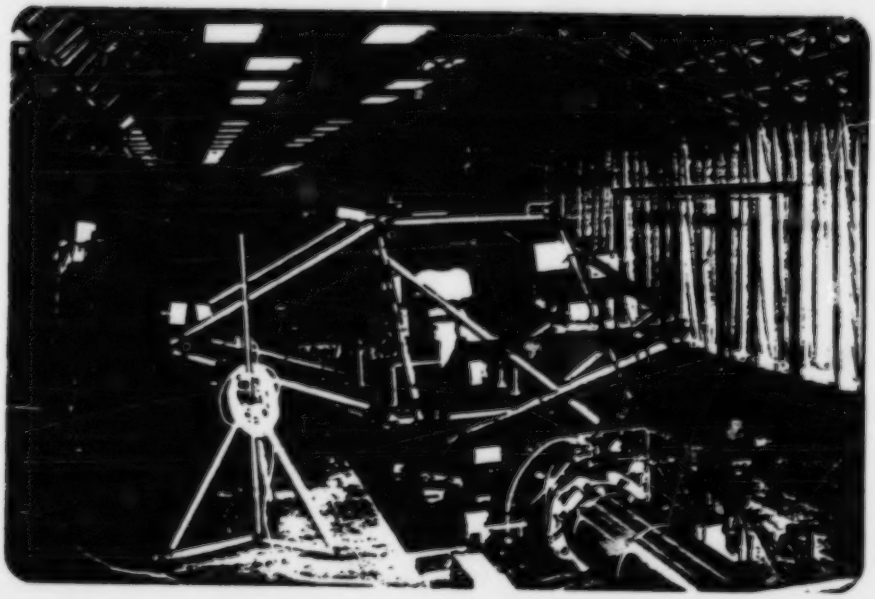
3) Three-point seat belt systems have potential to improve occupant protection, but further design work would be necessary by the bus manufacturers to reduce chest loading and to determine if it would be necessary to strengthen the floor construction.

4) The multi-point restraint system should not be considered further since problems were encountered with submarining. The system was also judged to be cumbersome and difficult to put on and adjust properly.

PHOTO INDEX

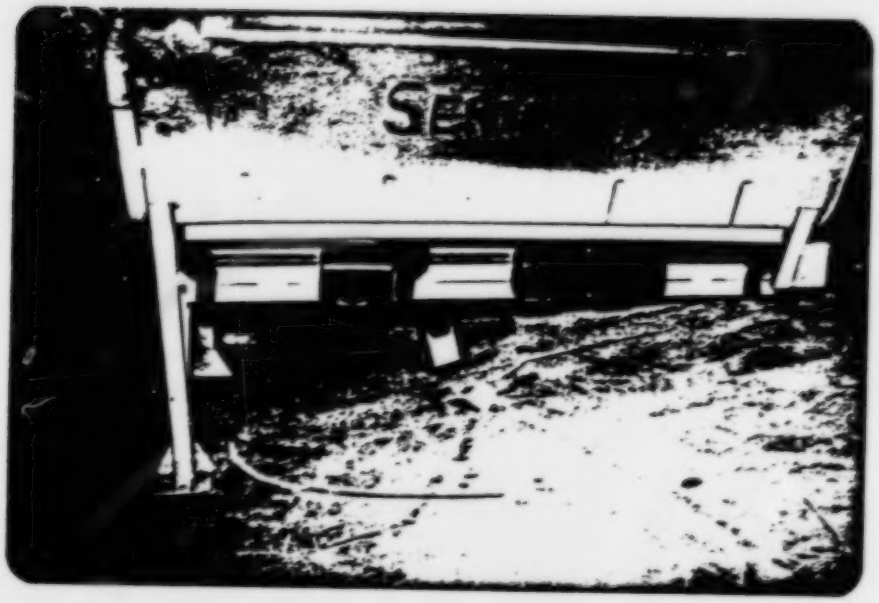
1. Test Sled DCIEM
2. Unaltered Blue Bird Seat - seat cushion removed
3. Typical retractor mounting on seat frame
4. Contour-Padded Seat - pre test profile
5. Less Aggressive Seat - frame construction
6. Less Aggressive Seat - frame upper corner detail
7. Three Point Restraint System - frame construction
8. Three Point Restraint System - rear of frame
9. Multi Point Restraint System - 3 seating positions
10. Multi Point Restraint System - upper belt anchorage
11. Rearward Facing Seat - frame construction
12. Rearward Facing Seat - frame - side view
13. Unaltered Blue Bird Seat - pre test
14. Unaltered Blue Bird Seat - post frontal test
15. Unaltered Blue Bird Seat - post frontal test - head & knee contact
16. Unaltered Blue Bird Seat - post frontal - seat back deformation
17. Contour Padded Seat - post frontal test - front belt spool-out
18. Contour Padded Seat - post frontal test - head & knee contact
19. Contour Padded Seat - pre oblique test
20. Contour-Padded Seat - post oblique test
21. Contour-Padded Seat - post oblique test - head & knee contact
22. Unaltered Blue Bird Seat - pre oblique test
23. Unaltered Blue Bird Seat - post oblique test - head & knee contact
24. Less Aggressive Seat - pre test
25. Less Aggressive Seat - post frontal test - front belt spool-out
26. Less Aggressive Seat - post frontal test - head & knee contact
27. Less Aggressive Seat - post frontal test - seat back deformation
28. Rearward Facing Seat - pre test - ATD head secured in lap
29. Rearward Facing Seat - post frontal test - deflection of seat back
30. Rearward Facing Seat - post frontal test - head & knee contact
31. Three Point Restraint System - pre test
32. Three Point Restraint System - pre test - belt fit
33. Three Point Restraint System - post frontal test

34. Three Point Restraint System - post frontal test - knee contact only
35. Multi Point Restraint System - pre test
36. Multi Point Restraint System - pre test - belt fit
37. Multi Point Restraint System - post frontal test
38. Multi Point Restraint System - post frontal test - knee contact only
39. Contour Padded Seat - post frontal test - broken retractor (typical)
40. Less Aggressive Seat - pre oblique test
41. Less Aggressive Seat - post oblique test
42. Less Aggressive Seat - post oblique test - head & knee contact
43. Three Point Restraint System - pre oblique test
44. Three Point Restraint System - post oblique test
45. Three Point Restraint System - post oblique test - knee contact
46. Multi Point Restraint System - pre oblique test
47. Multi Point Restraint System - post oblique test - submarining
48. Multi Point Restraint System - post oblique test - knee contact
49. Rearward Facing Seat - pre oblique test
50. Rearward Facing Seat - post oblique test - deflection of seat back
51. Countour Padded Seat - pre frontal test - unbelted ATD
52. Countour Padded Seat - post frontal test - front belt spool-out - unbelted ATD
53. Countour Padded Seat - post frontal test - head & knee contact - unbelted ATD
54. Countour Padded Seat - post frontal test - retractor broken - unbelted ATD
55. Less Aggressive Seat - pre frontal test - ATD at aisle seating position
56. Less Aggressive Seat - post frontal test - ATD at aisle - seat back deformation
57. Three Point Restraint System - pre frontal test - 2 ATD on seat
58. Three Point Restraint System - post frontal test - 2 ATD on seat
59. Three Point Restraint System - post frontal test - 2 ATD on seat - head & knee contact
60. Rearward Facing Seat - pre frontal test - 3 ATD on seat
61. Rearward Facing Seat - post frontal test - broken side support
62. Rearward Facing Seat - post frontal test - 3 ATD on seat
63. Rearward Facing Seat - post frontal test - 3 ATD on seat - deflection of back



1. Test Sled DCIEM

2. Unaltered Blue Bird Seat - seat cushion removed



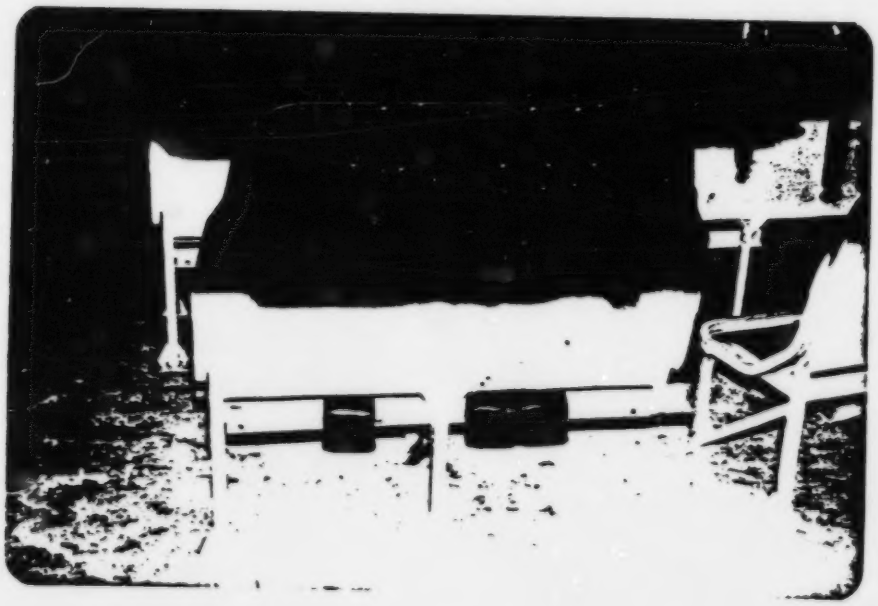
3. Typical retractor mounting on seat frame

4. Contour-Padded Seat - pre test profile

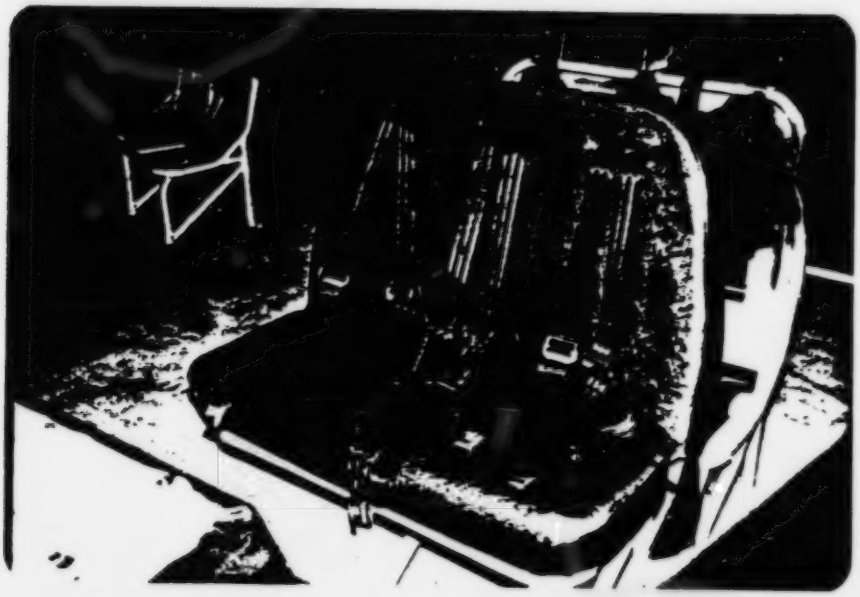
5. Less Aggressive Seat - frame construction

6. Less Aggressive Seat - frame upper corner detail

7. Three Point Restraint System - frame construction



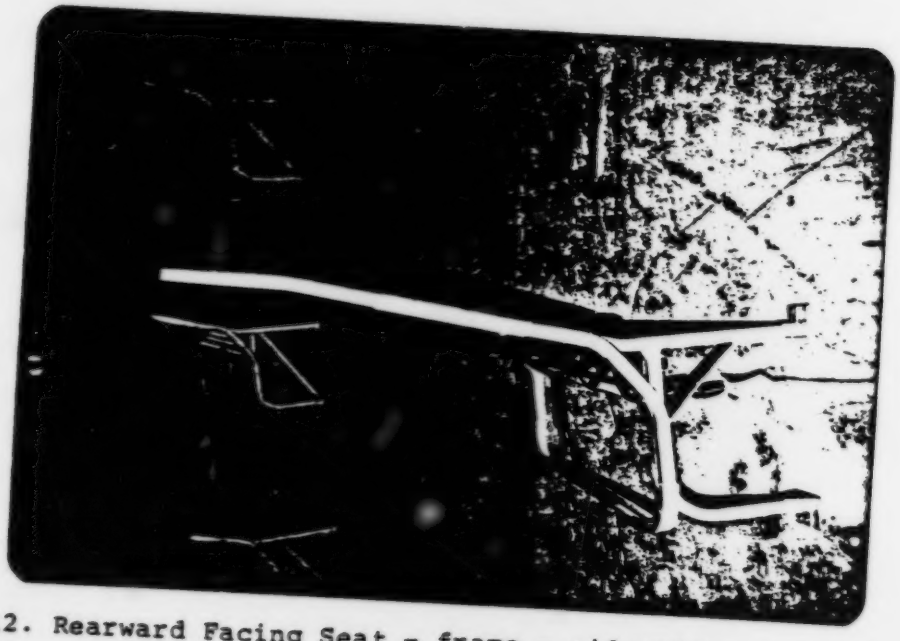
8. Three Point Restraint System - rear of frame



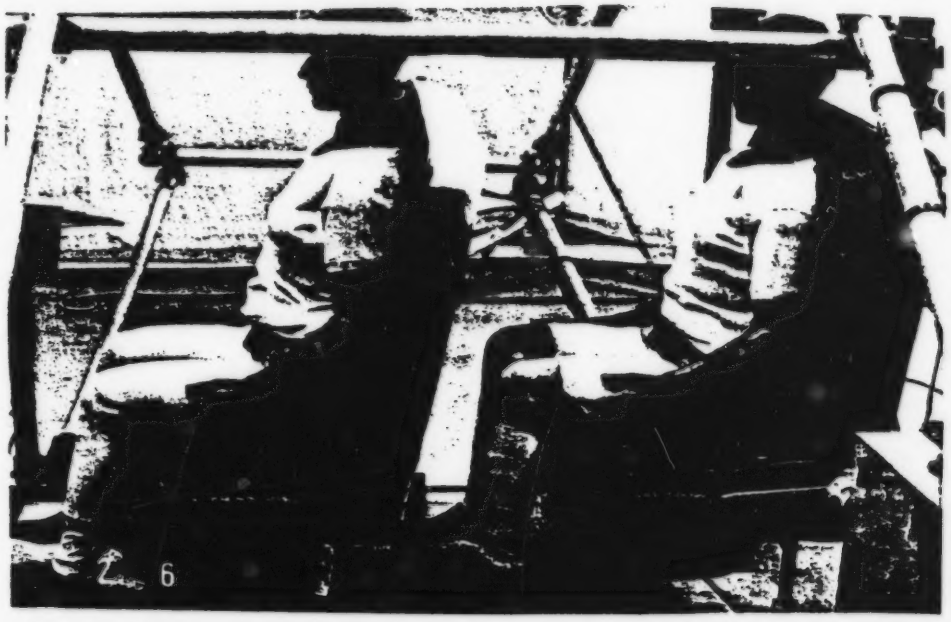
9. Multi Point Restraint System - 3 seating positions

10. Multi Point Restraint System - upper belt anchorage

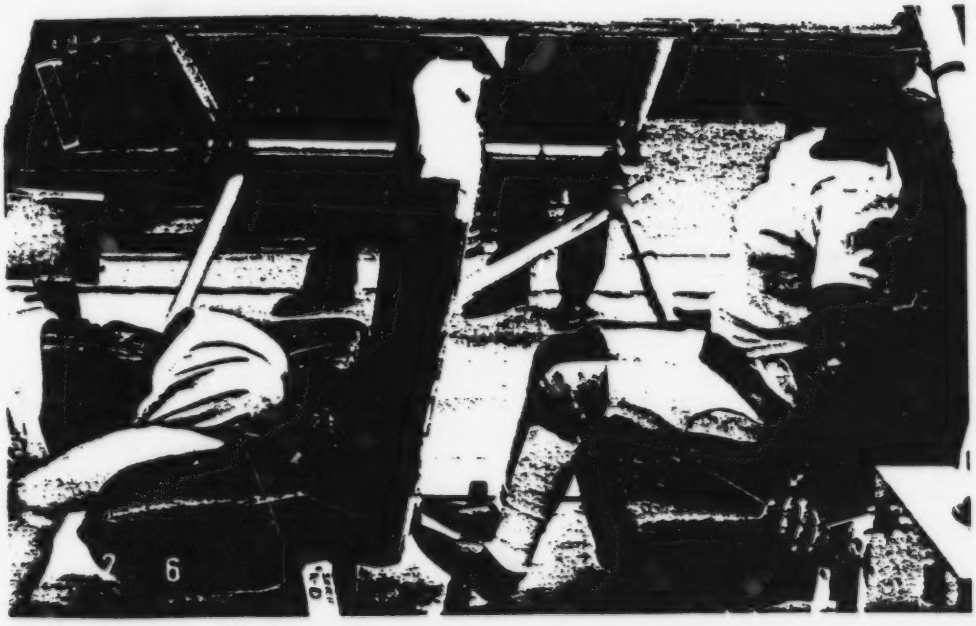
11. Rearward Facing Seat - frame construction



12. Rearward Facing Seat - frame - side view

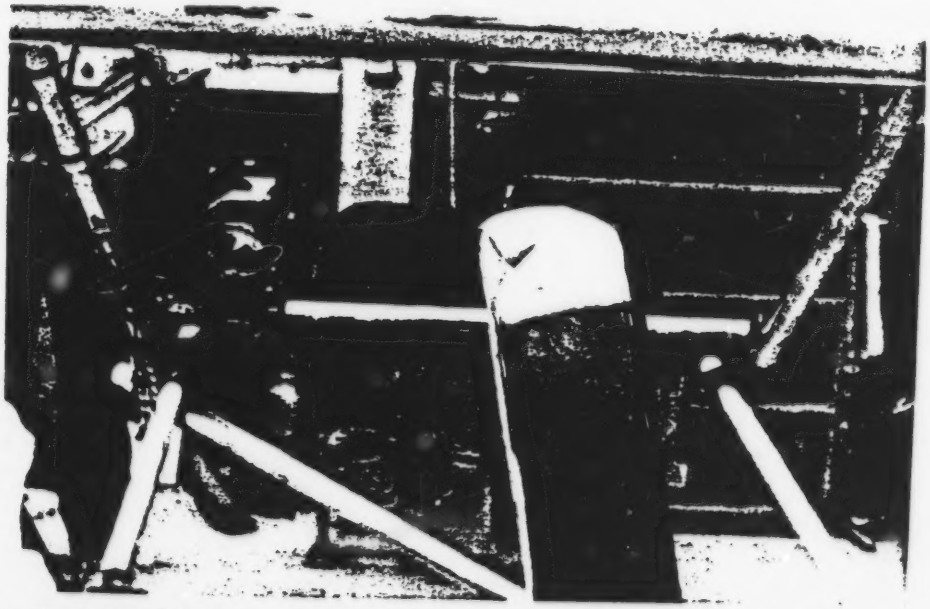


13. Unaltered Blue Bird Seat - pre test



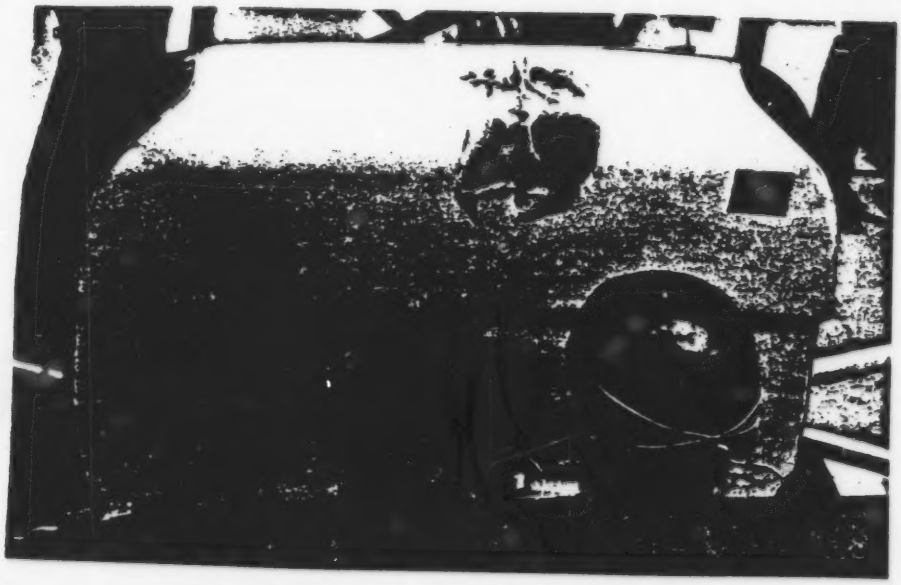
14. Unaltered Blue Bird Seat - post frontal test

15. Unaltered Blue Bird Seat - post frontal test - head & knee contact

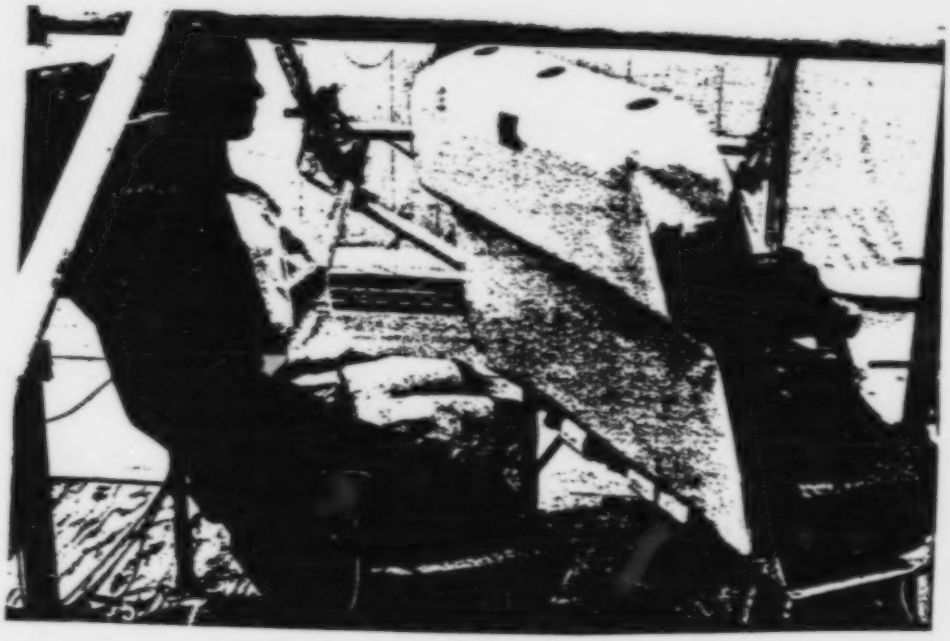


16. Unaltered Blue Bird Seat - post frontal - seat back deformation

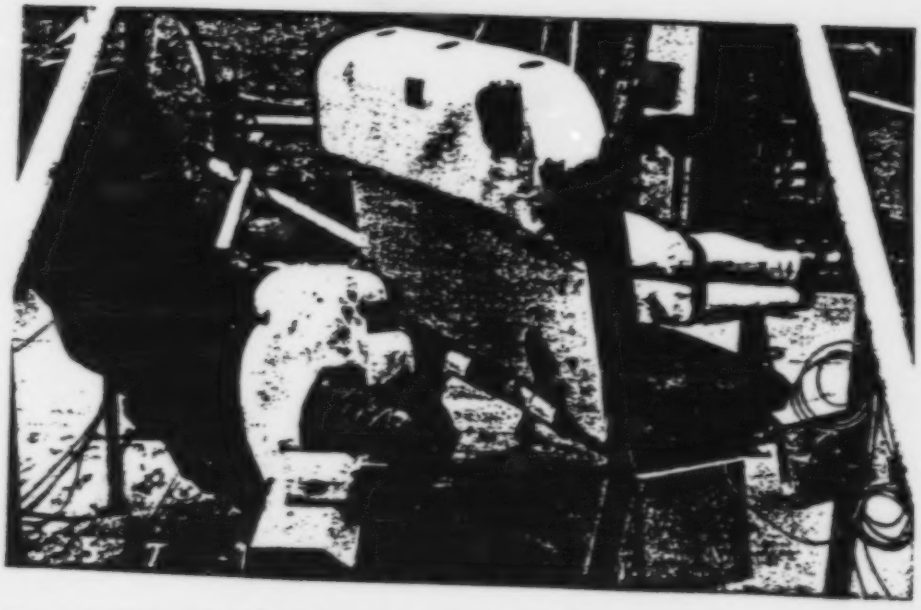
17. Contour Padded Seat - post frontal test - front belt spool-out



18. Contour Padded Seat - post frontal test - head & knee contact



19. Contour Padded Seat - pre oblique test

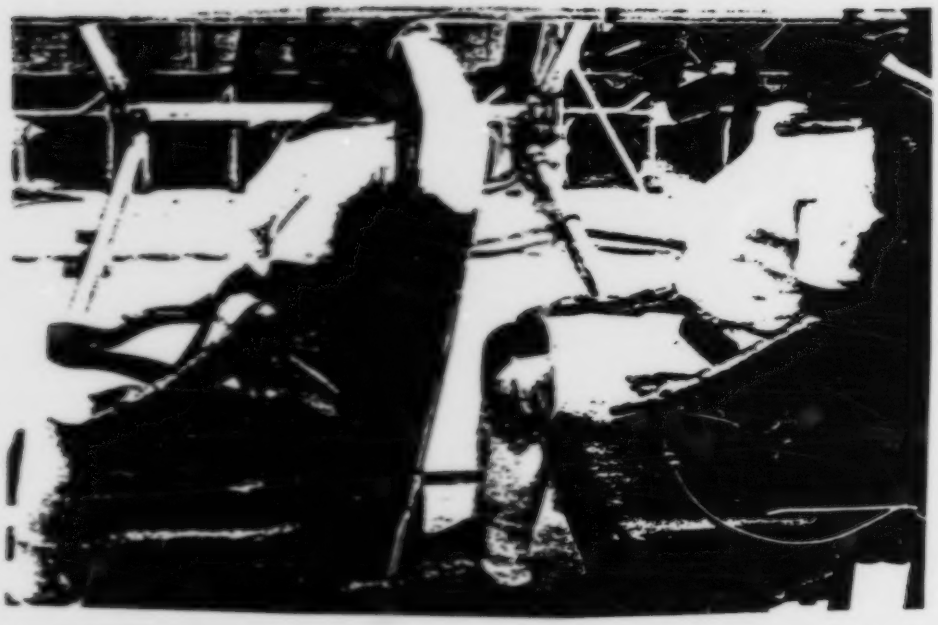


20. Contour-Padded Seat - post oblique test

21. Contour-Padded Seat - post oblique test - head & knee contact

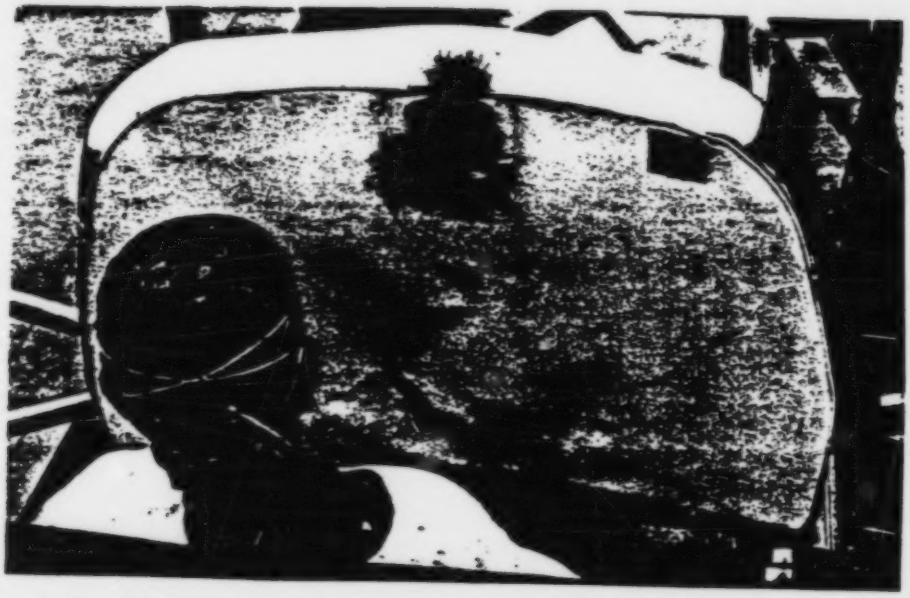
22. Unaltered Blue Bird Seat - pre oblique test

23. Unaltered Blue Bird Seat - post oblique test - head & knee contact



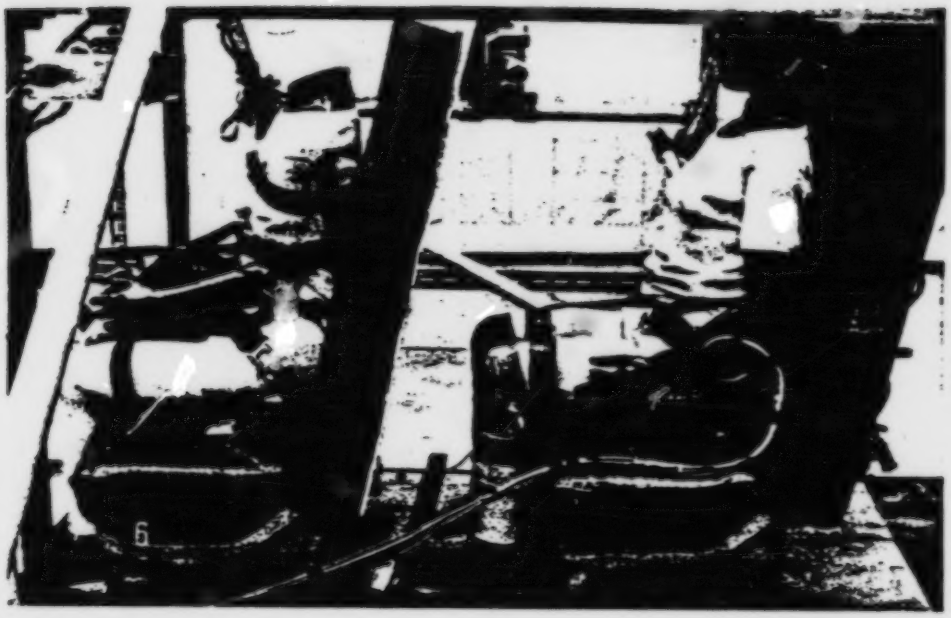
24. Less Aggressive Seat - pre test

25. Less Aggressive Seat - post frontal test - front belt spool-out

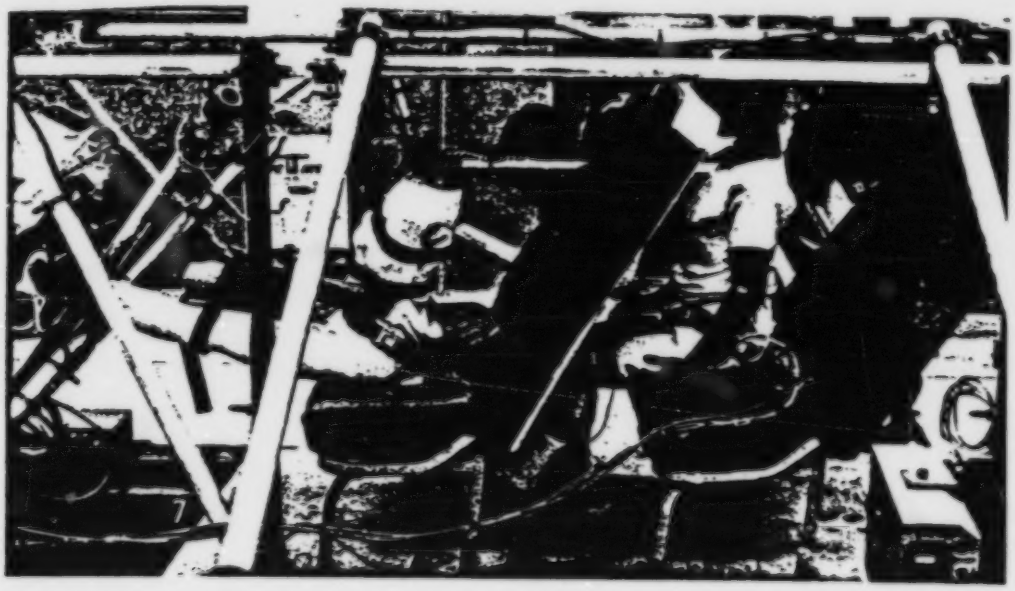


26. Less Aggressive Seat - post frontal test - head & knee contact

27. Less Aggressive Seat - post frontal test - seat back deformation



28. Rearward Facing Seat - pre test - ATD head secured in lap



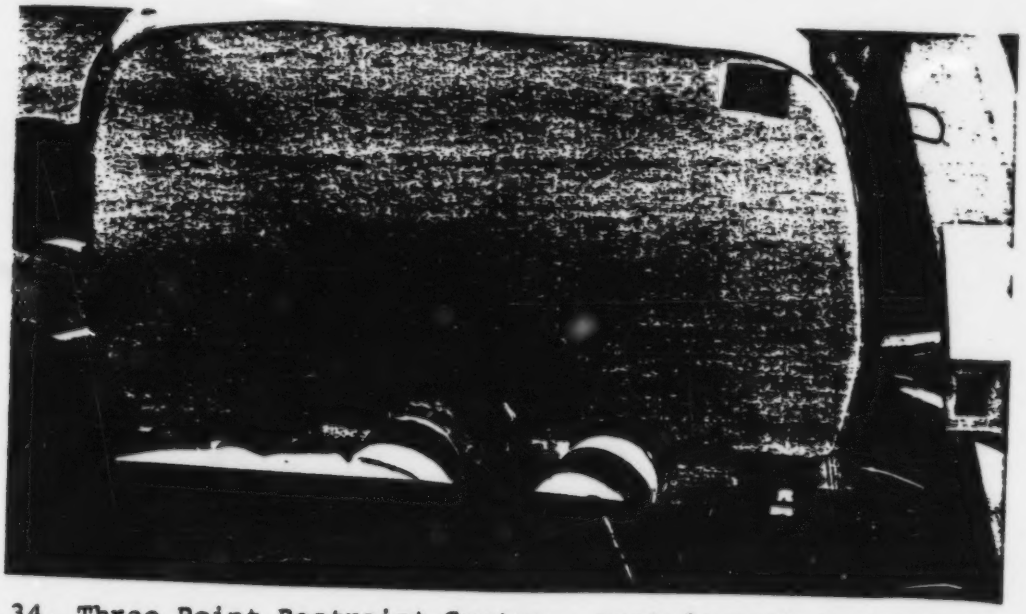
29. Rearward Facing Seat - post frontal test - deflection of seat back

30. Rearward Facing Seat - post frontal test - head & knee contact

31. Three Point Restraint System - pre test

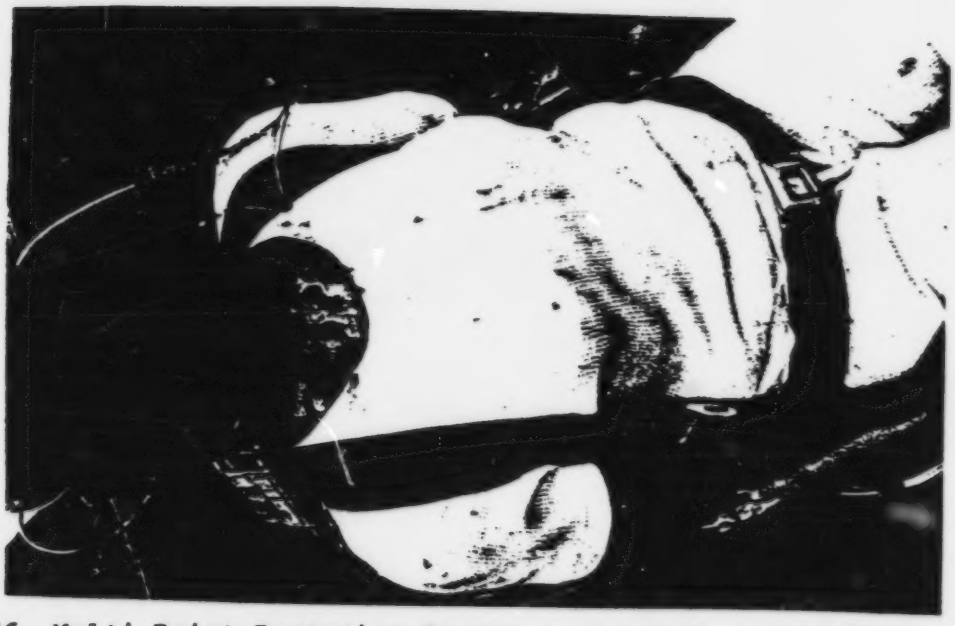
32. Three Point Restraint System - pre test - belt fit

33. Three Point Restraint System - post frontal test

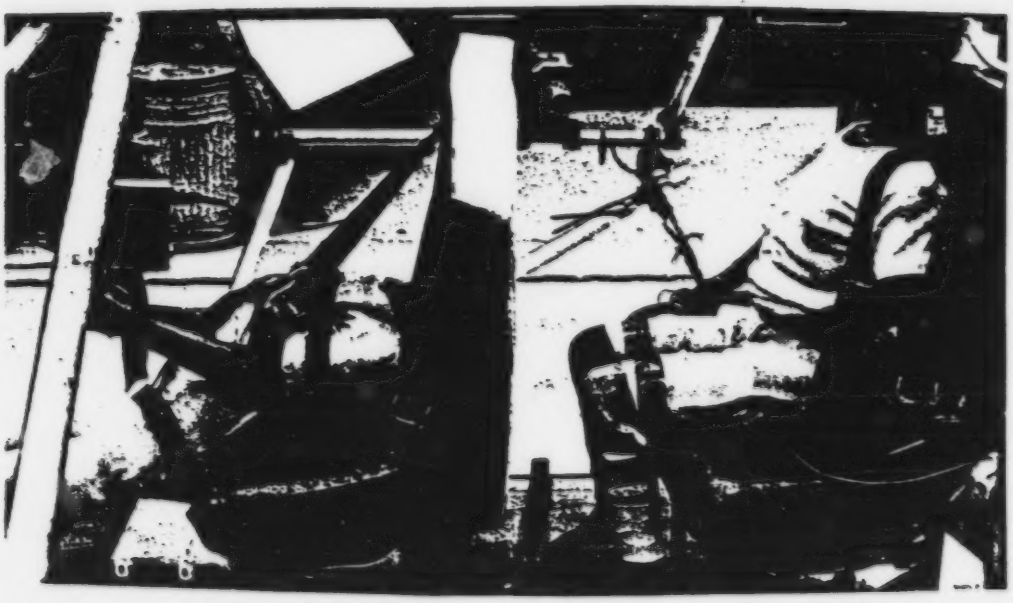


34. Three Point Restraint System - post frontal test - knee contact only

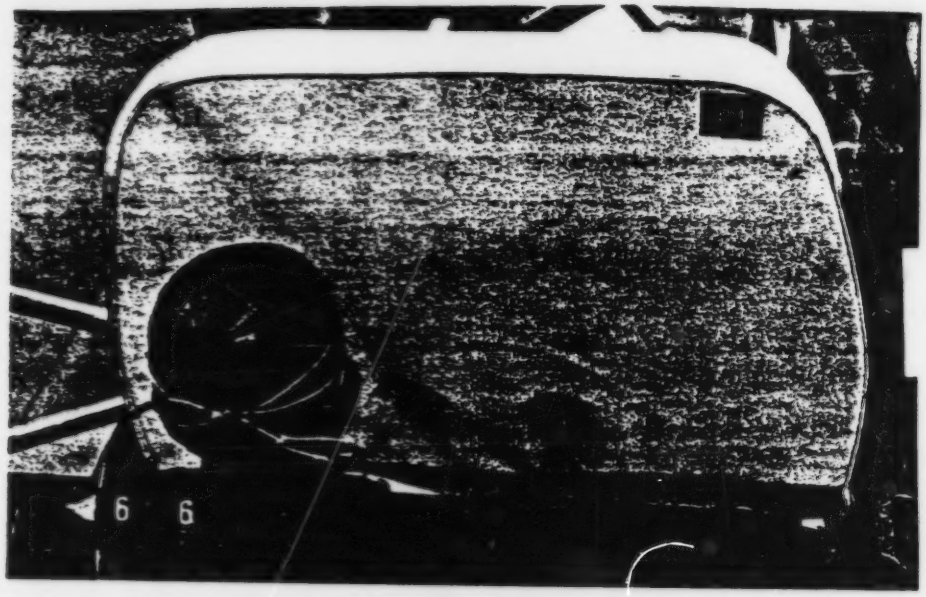
35. Multi Point Restraint System - pre test



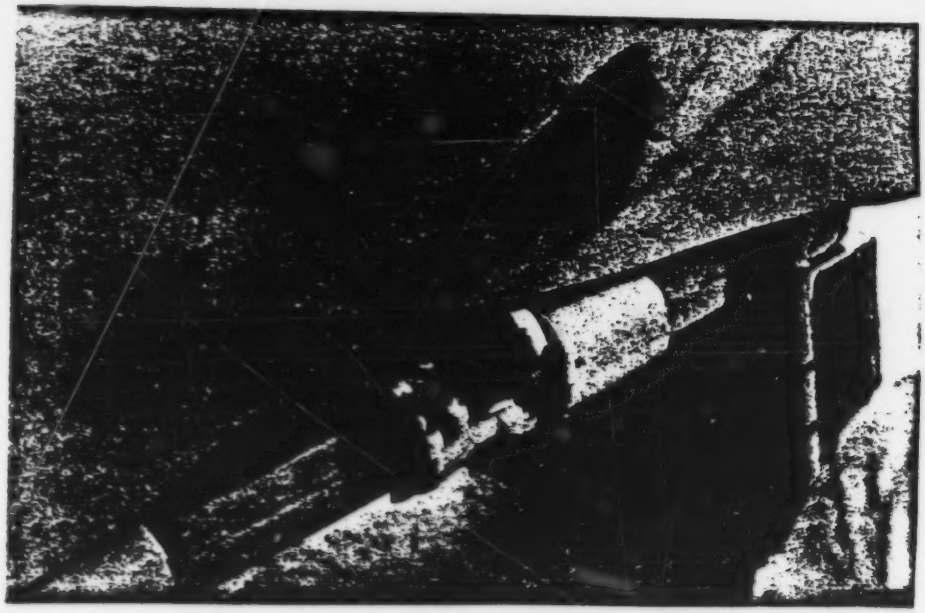
36. Multi Point Restraint System - pre test - belt fit



37. Multi Point Restraint System - post frontal test

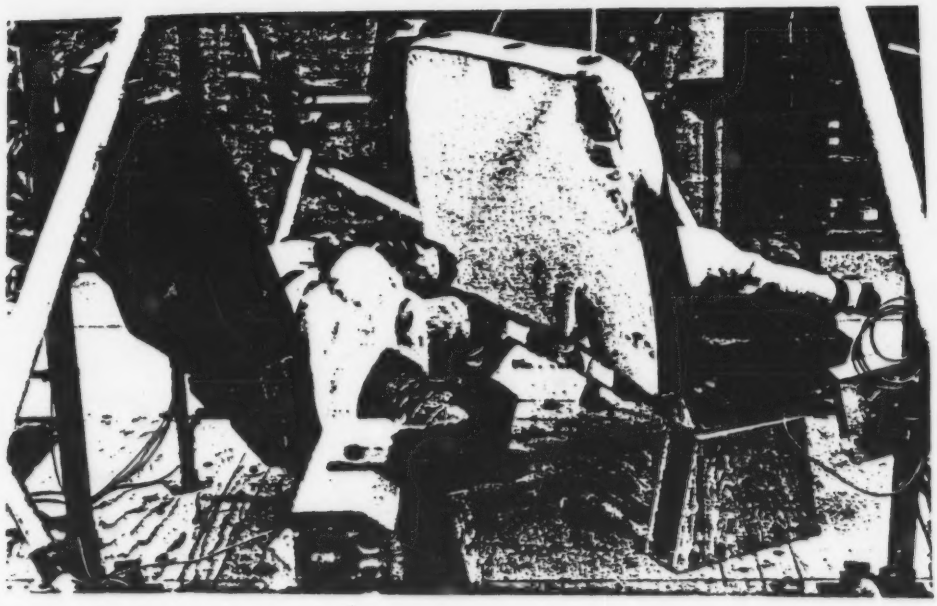


38. Multi Point Restraint System - post frontal test - knee contact only



39. Contour Padded Seat - post frontal test - broken retractor (typical)

40. Less Aggressive Seat - pre oblique test

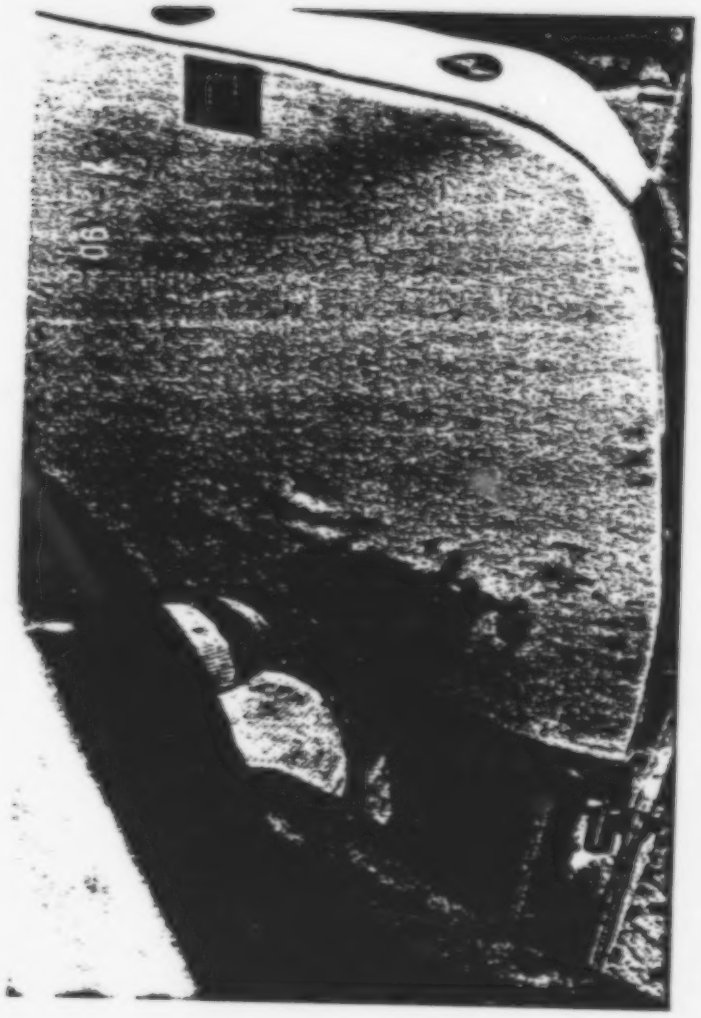


41. Less Aggressive Seat - post oblique test

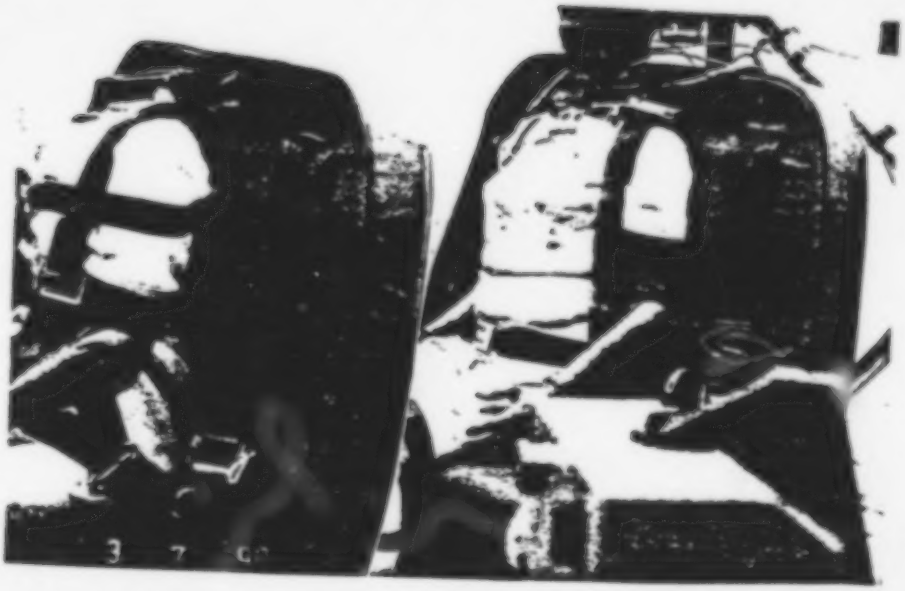
42. Less Aggressive Seat - post oblique test - head & knee contact

43. Three Point Restraint System - pre oblique test

44. Three Point Restraint System - post oblique test



45. Three Point Restraint System - post oblique test - knee contact

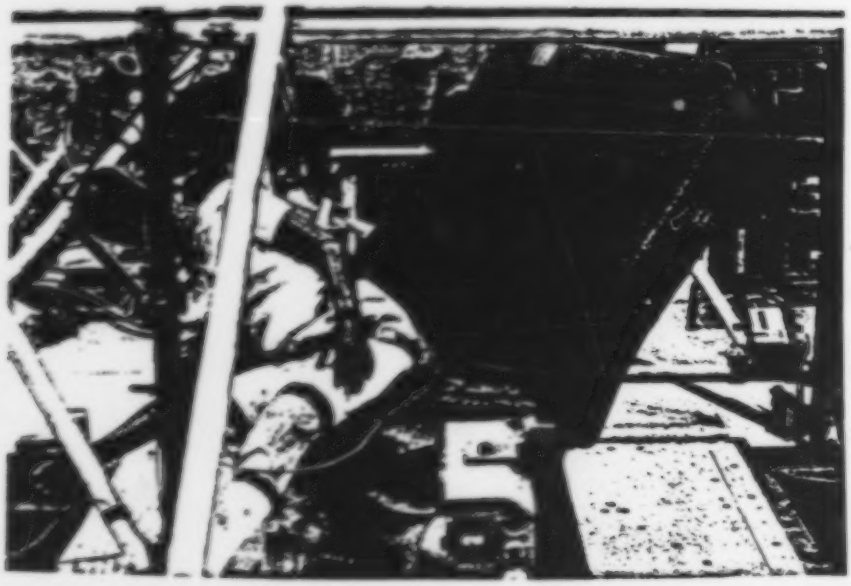


46. Multi Point Restraint System - pre oblique test

47. Multi Point Restraint System - post oblique test - submaring

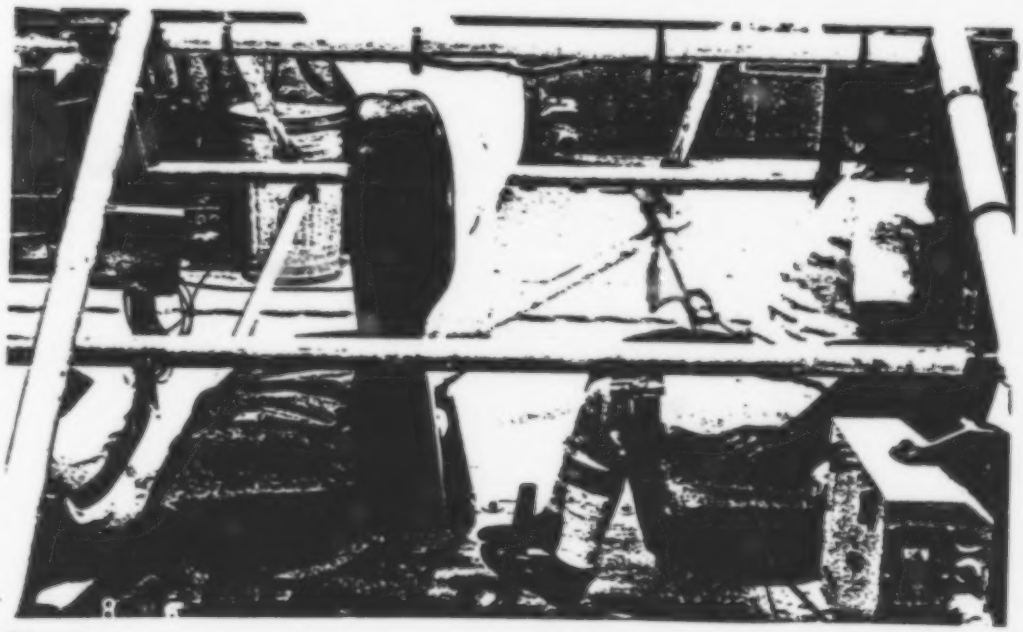
48. Multi Point Restraint System - post oblique test - knee contact

49. Rearward Facing Seat - pre oblique test

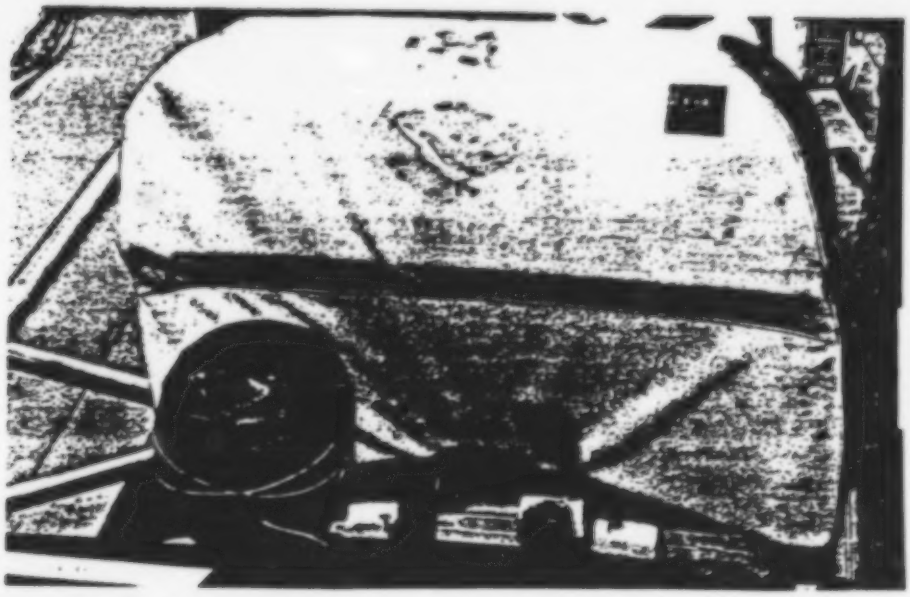


50. Rearward Facing Seat - post oblique test - deflection of seat back

51. Countour Padded Seat - pre frontal test - unbelted ATD

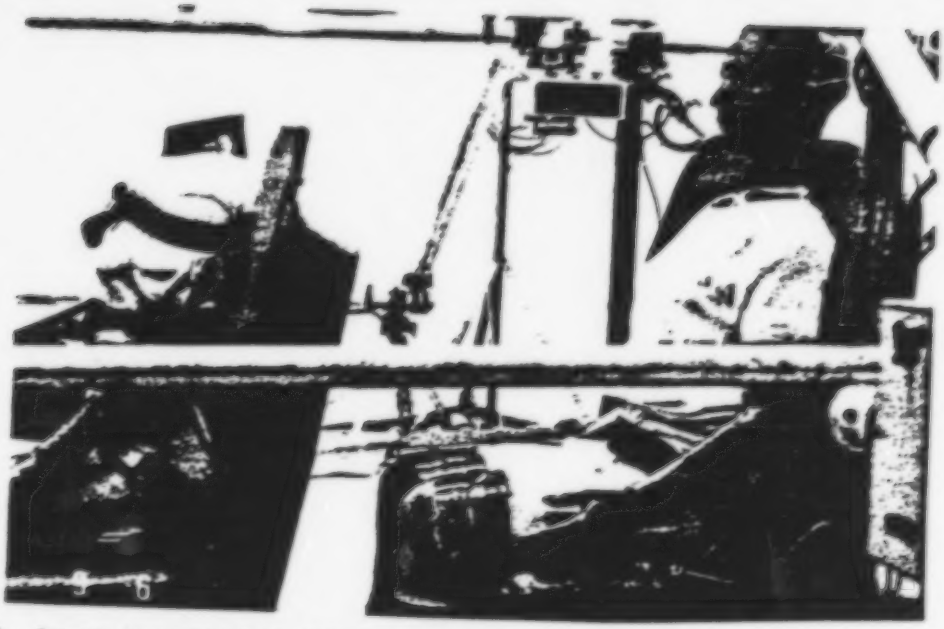


52. Countour Padded Seat - post frontal test - front belt spool-out - unbelted ATD

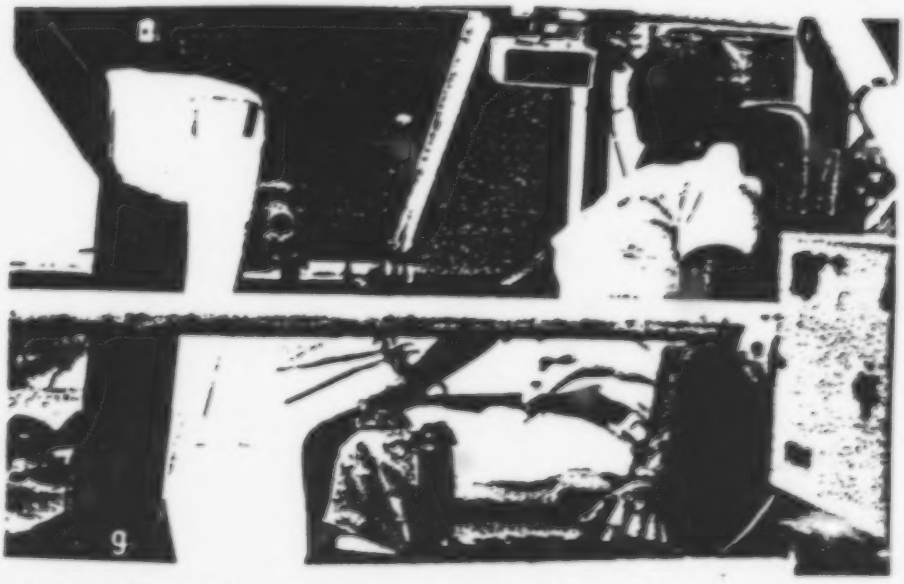


53. Countour Padded Seat - post frontal test - head & knee contact - unbelted ATD

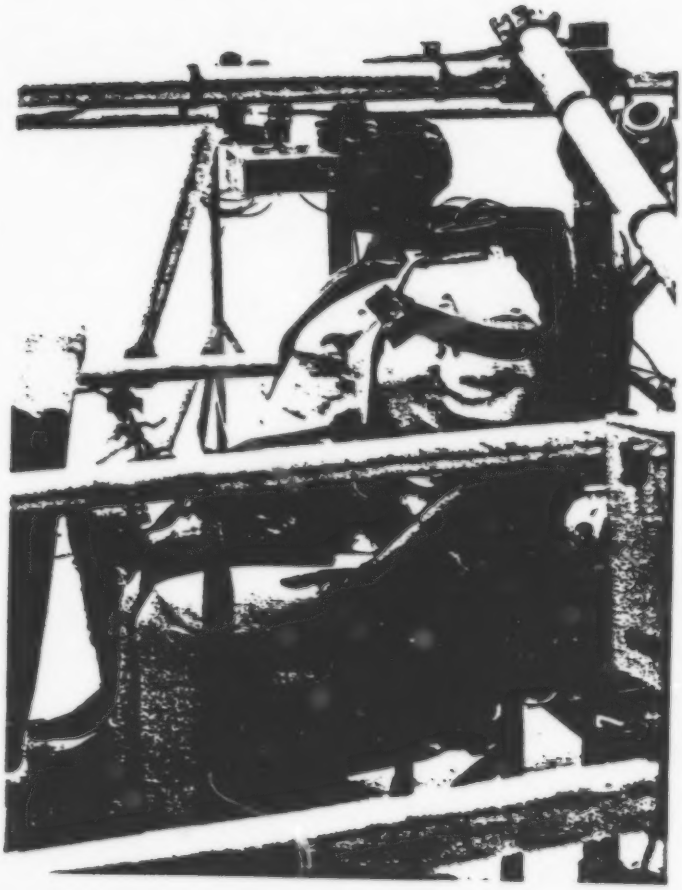
54. Countour Padded Seat - post frontal test - retractor broken - unbelted ATD



55. Less Aggressive Seat - pre frontal test - ATD at aisle seating position

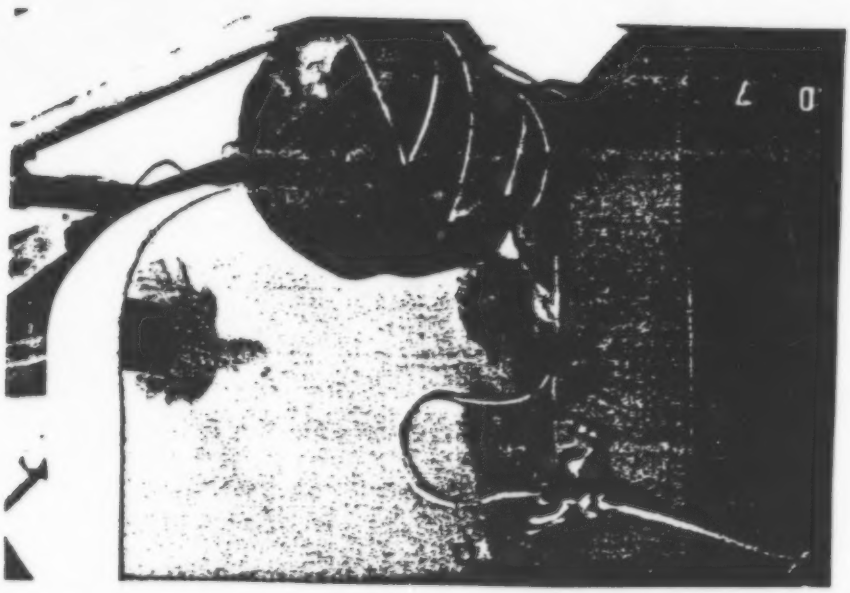


56. Less Aggressive Seat - post frontal test - ATD at aisle - seat back deformation

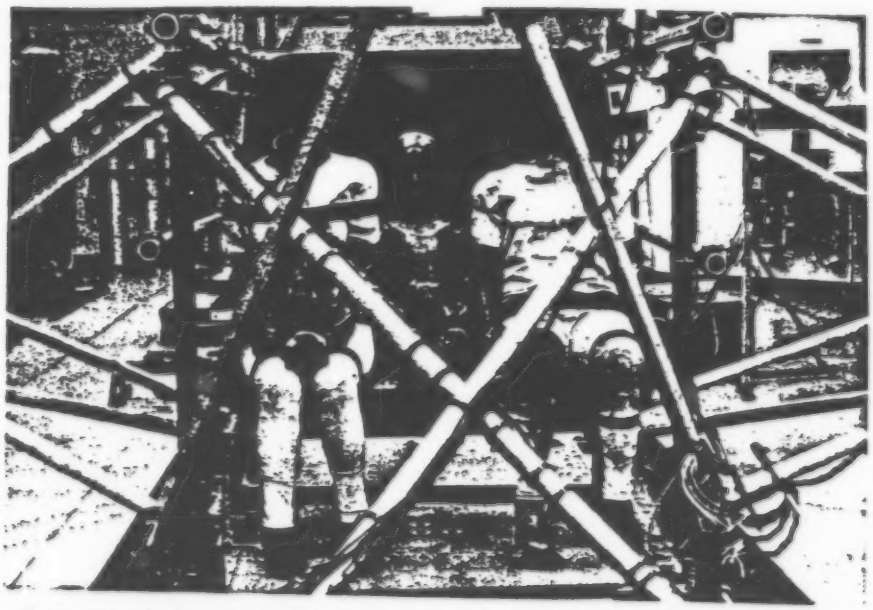


57. Three Point Restraint System - pre frontal test - 2 ATD on seat

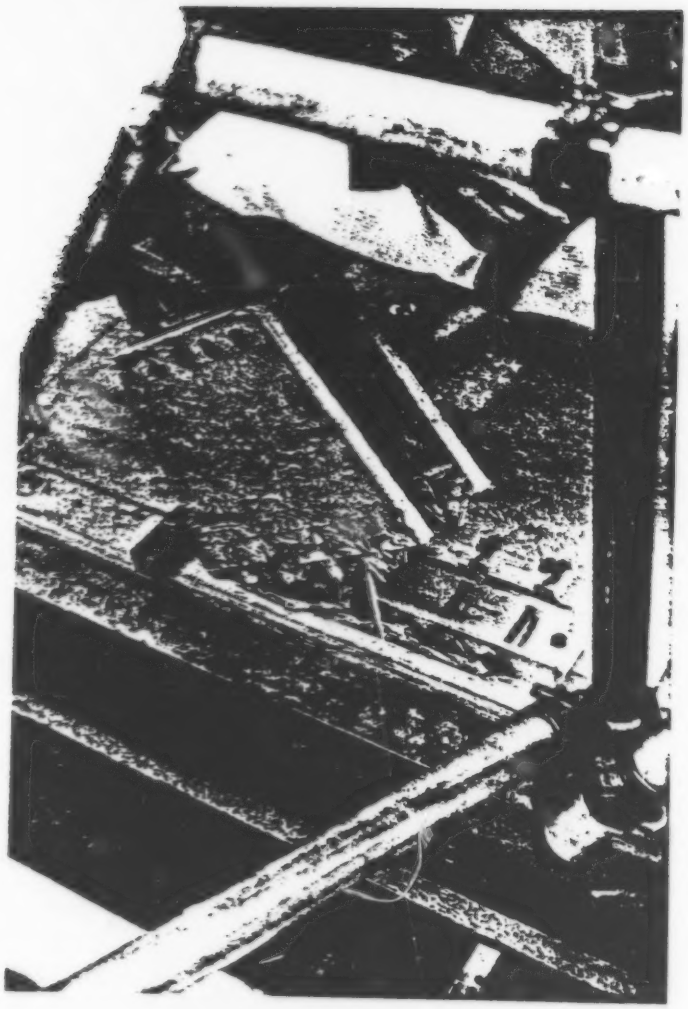
58. Three Point Restraint System - post frontal test - 2 ATD on seat



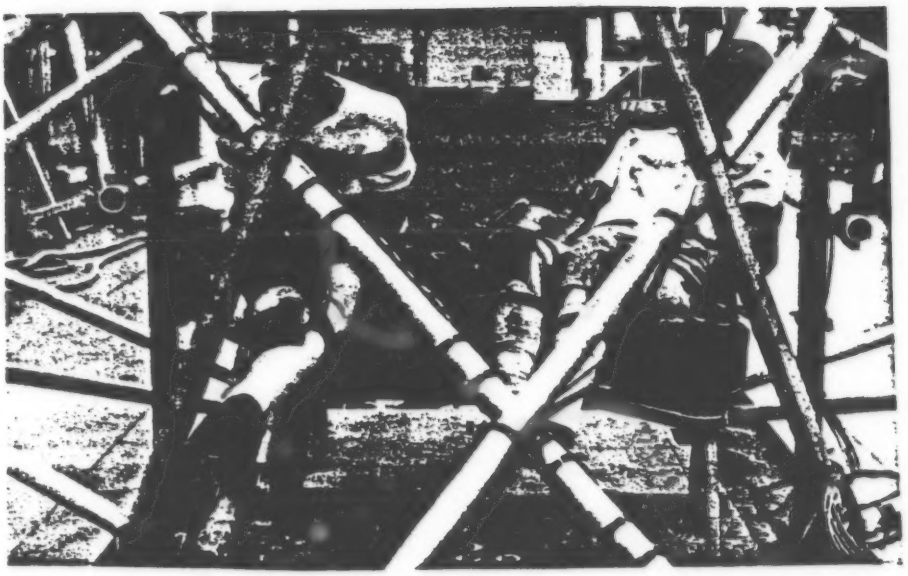
59. Three Point Restraint System - post frontal test - 2 ATD on seat - head & knee contact



60. Rearward Facing Seat - pre frontal test - 3 ATD on seat



61. Rearward Facing Seat - post frontal test - broken side support



62. Rearward Facing Seat - post frontal test - 3 ATD on seat

63. Rearward Facing Seat - post frontal test - 3 ATD on seat - deflection of back

REFERENCES

1. Farr G.N., Transport Canada, "School Bus Safety Study" Volume 1, January 1985.

2. Davis Engineering Ltd., "School Bus Seat Development Study", prepared for Traffic Safety Standards & Research, Transport Canada, October 1986.

3. Gutoskie P., Transport Canada, "School Bus Accident Study", July 1978 (TMSE 7801).

4. CMVSS 222 "School Bus Passenger Seating and Crash Protection".

5. CMVSS 217 "Bus Window Retention, Release and Emergency Exits".
   CMVSS 219 "Windshield Zone Intrusion".

6. CMVSS 221 "School Bus Body Joint Strength".

7. CMVSS 301 "Fuel System Integrity".

8. CMVSS 220 "Rollover Protection".

9. TES Ltd., "An Investigation of Safety Shields for School Bus Seats", March 1984, prepared for Transport Canada (TP 348E).